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Musculoskeletal injuries are common among military recruits: incidence rates of 20-90% have been reported. Of these, as many as 87% are due to overuse. The objective of this project was to predict individual's susceptibility to muscle overuse injury based on their pattern of weakness and to develop ways of preventing and treating these overuse injuries. The hypothesis is that focal weakness predisposes to overuse syndromes related to the weakened muscles and/or those used in compensatory movement strategies. The muscle weakness experienced by many polio survivors results in a pattern of accelerated overuse. This puts this population in a unique position to serve as an accelerated model forthe same weakness-overuse-injury cycle experienced by military recruits and occupational athletes.

Muscle strength, range of motion, and symptomatology data have been collected on 194 polio survivors and 226 able-bodied subjects. Among polio survivors, overuse symptoms were most common in the wrist, shoulder, knee and foot. There was a decrease in the mean strength of several muscle groups among polio survivors over a 6-9 month period. Several models were developed to define the relationship between specific areas of muscle weakness and overuse symptoms. In many cases, early results support the *a priori* predictions.

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INTRODUCTION

Although there have been numerous studies dealing with muscle physiology, tissue response to injury, kinesiology (muscle use), kinematics (joint motion), and kinetics (force application), most of these studies have remained laboratory-based. Generally, this knowledge has not been applied to everyday clinical situations, occupational demands, or military training protocols. Efforts to apply laboratory technology and knowledge in this field of research have been directed toward a very small group: the elite professional or Olympic athlete. Minimal efforts have been undertaken to address the needs and demands placed on "occupational athletes", "military athletes", or "Activities of Daily Living (ADL) athletes".

The ADL athlete is perhaps the least appreciated and understood. The strength and energy demands of common daily activities are greater than realized. They necessitate great endurance as well as durability and strength. The demands of specific common activities, such as rising from a chair, are largely unknown. Likewise, many studies have documented the high rate of injuries suffered by military recruits during initial weeks of training, which may push unconditioned muscles to or beyond limits of endurance.[1,2,3,4] Even less understood are the compensatory mechanisms used when there is muscle weakness or pain.

The relationship between muscle weakness, overuse, and injury, is one that has received much clinical attention. Muscle weakness can be found in an unconditioned individual, after injury, or after illness, and may arise for a variety of reasons:

• Chronic weakness in a given muscle group may result from a neurologic disease (e.g. polio) or an extremity injury. For example, there is evidence that muscle atrophy, weakness, and abnormal motor patterns may persist at least one to five years after an injury requiring immobilization[5], may affect distant, uninjured muscle groups[6], and may not resolve without conscious retraining.[7]

• Transient weakness results directly from a fatiguing task or pain-limitation on full muscle recruitment.[8] A pitcher in a ball game for a full nine innings would suffer transient weakness in his throwing arm.[9]

• Under certain conditions requiring higher than normal tasks demands, a muscle or group of muscles of normal strength may display relative weakness. An unconditioned individual required to run ten miles, or a non-weight lifter trying to lift 500 lbs. would fall into this category.

Obviously, these various etiologies produce weakness of different kinds, but each may lead to overuse of muscles to carry out certain tasks. The overuse can occur directly: weak muscle themselves need to work harder to maintain a certain force, thus becoming overused. The overuse may also be incurred indirectly, in alternate muscles that are recruited to compensate for the weak ones. Moreover, the relationship between focal weakness, focal overuse, and injury is both a cyclical and a reciprocal one, weakness producing overuse, overuse causing further weakness, and both predisposing to injury. (See Figure 1 in Appendix I) The injury can occur in the muscles themselves or in joint, capsule, or bone, since overused muscles are less capable of protecting these structures.[1,2]

Many polio survivors enter the weakness-overuse-injury cycle with chronically weak muscles. Military recruits most probably enter either with overuse or transient or relative weakness, induced by an unconditioned individual starting a rigorous training regimen. ADL athletes may enter at any point, two examples being surgery-induced weakness or repetitive demands leading to overuse (as in carpal tunnel syndrome by data entry personnel).

Though each of these populations enter the cycle at different points and at different levels of weakness, once in the cycle they are all prone to injury via the same biomechanical mechanisms. For this reason, polio survivors provides an excellent model for the study of all overuse disorders. The muscle weakness experienced by many polio survivors causes accelerated overuse, allowing the overuse to be readily observed in a small population over a short period of time. Over time, polio survivors

become masterful in a wide variety of compensatory techniques. Therefore, they also provide an excellent model to study the nature of compensatory muscle use and the induction of secondary injuries.

Muscle Overuse and Trauma in Military Recruits and ADL Athletes

Musculoskeletal injuries are alarmingly common in military recruits: incidence rates of 20-90% gave been reported.[1,3,4,10,11,12,13] Of these, as many as 87% are due to overuse.[10] The bulk of these overuse injuries occur in the initial weeks of training, when rigorous physical demands represent an extreme increase in activity level for almost all recruits. As with polio survivors, most injuries are in the lower limbs. Musculoskeletal disorders are increasing in the military and, by 1991, accounted for 67% of medical discharges, incurring a cost to the Air Force of at least $2.7 million over five years.[3] These disorders can also lead to diminished combat performance, as evidenced by evacuation hospital findings in Operation Desert Storm and Operation Uphold Democracy.[14,15]

A variety of factors in military training programs have been implicated in these injuries, including: exercising when fatigued, length of marches, training surface, arrangement of platoons (allowing shortest recruits to set stride length by placing them in front may reduce injury), stamping of feet on asphalt when coming to attention, design and fit of boots, carrying heavy weights overhead, and training techniques, including increasing the intensity, duration, or frequency of training too rapidly.[1,16] Thus, simple adjustments to training regimens could produce significant improvements injury rates.[2] Additional factors that have been implicated in military overuse injuries include: prior exercise regimen and level of physical conditioning, running history, emotional status, and environmental factors, such as the height of obstacles on a training course.[3] More research needs to be done, however, to determine the extent and relative importance of each predisposing factor.

Among civilians, occupational activities and recreational exercise are the most common sources of muscle overuse and injury. According to Renstrom, the yearly incidence of running injuries is between 37% and 56%. Increases in activity intensity, injury history, muscle weakness, and idiopathic biomechanics have been implicated in the etiology of athletic injuries.[17]

Prevalence of Subclinical Focal Weakness in Military Recruits and ADL Athletes

Though not much is known about the incidence of subclinical focal weakness in normal individuals, significant paresis can exist in individuals who are diagnosed as "normal" by manual muscle testing, and who function and feel normal in active daily life.[18] Moreover, the population from which the military secures its recruits, i.e. active, athletic young adults, are the same individuals most likely to have suffered some kind of injury due to athletics. Such injuries have a "subclinical" effect on muscle operation long after full recovery is assumed.[5,6]

Transient or relative weakness may be very common in this population given the high intensity nature of training. It should be emphasized that in such a healthy, fit population biomechanical compensation can allow an individual to continue activity at a normal level. In this situation he or she may be overusing muscles to compensate for an undetected subclinical focal injury or weakness and thus, do permanent muscular damage.

Overt and Subclinical Weakness Produced by Polio

There are 1.5 million people in America who have residual paralysis from poliomyelitis. At present approximately 40% of these people have experienced a significant decline in their ability to function in recent years. This functional decline has been called Post-Polio Syndrome (PPS). PPS is usually diagnosed 30-40 years after the initial polio infection. All individuals with prior polio are at risk for developing PPS unless they receive preventative treatment.

PPS is characterized by a number of symptoms, including increasing muscle weakness, muscle and joint pain, incapacitating fatigue, and depression.[19,20,21] The loss of muscle strength can be perceived as sudden and severe. Additional symptoms include intolerance to cold, muscle atrophy, fasciculation, and sleep disorders.[19,21]

The major cause of PPS is thought to be the chronic overuse of muscles which were weakened by polio. In one study of PPS patients, polio-affected muscles were found to have strength values less than half those of healthy controls, mean fiber areas twice those of healthy controls, and low oxidative enzyme activity.[21]

Strength and endurance tests have revealed PPS patients to have significant deficits in neuromuscular function: in one study, PPS subjects had only 54% of normal strength and 51% of normal work capacity.[19] Another experiment, which evaluated the gait cycle of PPS patients, found that 85% of the subjects displayed excessive activity in at least two muscles. Despite this increased effort level, subjects' mean free gait velocity was significantly lower than normal.[20] Thus, in a walking task, PPS patients need to overexert muscles even to achieve a subnormal result. These results were obtained even in patients classified as "strong" and who earned manual muscle testing grades of "good" and "normal".

Furthermore, it has been shown that PPS individuals needing to use a much higher portion of maximal effort than normals to carry out a given task suffer significantly diminished endurance capacities and extended recovery time.[19]

Overuse Injuries in PPS

Over time, PPS patients become adept at compensating for this well-documented

weakness.[20, 22] The result is overuse and trauma to compensating muscles as well as those weakened by the initial polio infection. Moreover, the problem is exacerbated by the fact that patients seem willing to accept chronic pain as "the price" of having had polio, and many suffer for years, often denying their pain and weakness, and incurring further damage to muscle tissue, before requesting clinical help. The most common overuse injuries observed in this population as part of the Einstein-Moss Post-Polio Management Program are shown in Figure 2 (in Appendix I).

Post-Polio Syndrome as a Model for Muscle Overuse and Trauma in Military Recruits and ADL Athletes

The extensive muscle weakness experienced by many polio survivors results in a pattern of accelerated overuse and, often, subsequent trauma. This puts polio survivors in a unique position to serve as an accelerated model for the same weakness--overuse--injury cycle experienced in normal populations, such as military recruits and ADL athletes.

An important point to note is that although the muscle weakness of the polio survivor is more pronounced than that noted in the general population, polio is not a primary muscle disease, so normal muscle physiology, sensation, and motor control are preserved.[20] It is thus a "pure" model for study of the effects of muscle weakness on the remainder of the musculoskeletal system, namely muscle, tendons, ligaments, and joints.

Thus, this well-defined post-polio population is enabling researchers from the Albert Einstein Healthcare Network (AEHN), to study the effects of muscle weakness and overuse more efficiently. The hypotheses being tested by the proposed studies should help to elucidate: the relationship between overuse and trauma; the effectiveness of various interventions in breaking this cycle of muscle abuse, and the potential ability to predict what specific injuries may result from specific weaknesses.

STUDY #1: CROSS-SECTIONAL STUDY OF THE RELATIONSHIP BETWEEN PATTERNS OF WEAKNESS AND PATTERNS OF OVERUSE SYMPTOMS IN POST-POLIO SURVIVORS

RATIONALE:

If it is the case that specific muscle weakness leads to overuse both of the weakened muscle(s) and of those used to compensate for its weakness, then one would predict that identification and treatment of localized muscle weakness could lower the risk of development of overuse symptoms. The first step along this path was to establish a systematic relationship between the presence and location of weakness and the prevalence and location of overuse symptoms.

OBJECTIVES:

1) to determine the pattern of muscle weakness seen in the trunk and extremities in PPS;

2) to determine the prevalence of soft tissue overuse disorders and injuries

3) to determine the relationship of muscle weakness to the specific observed overuse injuries, both direct and compensatory.

METHOD

Subjects

A total of 194 polio survivors (98 male and 96 female) were recruited from the Einstein-Moss Post Polio Management Program and the community at large (including the surrounding four-state area: Pennsylvania, New Jersey, Delaware, and southern New York) to participate in this study. The criteria used in subject selection was as follows:

1) history of polio

2) no major disability unrelated to polio that could cause weakness or overuse problems

(e.g. stroke, amputation, diabetes, inflammatory arthritis, peripheral neuropathy, muscular dystrophy, congenital malformation)

3) no serious illness such as heart or lung disease which would make it unsafe for the subject to exert him/herself in a strength test (i.e. severe emphysema, poorly controlled asthma, resting angina, recent heart attack, recent treatment for an uncontrolled heart problem)

4) no fractures within six months of study enrollment

Procedure

The following protocol had the approval of the AEHN Institutional Review Board. Informed consent to participate in the study was obtained from all subjects prior to testing, and no adverse events occurred during testing.

Each subject was seen in the Post-Polio Research Clinic, following a standard procedure. To ensure diagnostic reliability and minimize bias throughout the study, one clinician evaluated strength and another symptomatology, each blinded from the other's evaluation.

Before any testing, a nurse conducted a brief clinical interview to review a standardized history which included an inventory of activities that may predispose to overuse symptoms. This self-administered activity assessment survey was developed based on a questionnaire designed to measure habitual physical activity.[23] Once the history and activity forms were completed, the subject's height (cm) and weight (kg) were measured using a standard scale.

A symptomatology evaluation was then conducted. The nurse started at the shoulder and using palpation in combination with tests for specific overuse symptoms, looked for areas of pain or tenderness. Each subject was also assessed for deformities common among polio survivors. The major joints were examined using tests which were specific for each joint. These tests are listed in Table 1 in

Appendix II. A positive or negative response was recorded for each test. If the response was positive for a symptom test, the subject was asked to rate their pain on a visual analog scale (VAS). This scale consisted of a 100 mm vertical line with the words "No Pain" at the bottom end and "Pain as bad as it could be" at the top end. The subject put a line on the scale corresponding to their feeling of pain or discomfort. They were also asked to identify the estimated date of onset of the pain and whether there were any specific activities which seemed to aggravate their symptoms. Once the symptomatology evaluation was completed, the nurse measured the true leg length and the thigh and calf circumference for both legs. This was followed by the range of motion evaluation for all major joints. A minimum of two trials were completed for each joint.

During this examination, if the nurse determined, based on the VAS rating, that there was significant pain which would interfere with accurate strength measurement (VAS > 50), she offered the subject an injection of local anesthetic. Injections consisted of 10 cc of Lidocaine. The maximum number of injections that a subject could receive was determined by the subject's weight. Subjects who weighed less than 65 kilograms were given one injection at most. Subjects who weighed more than 65 kilograms were allowed up to two injections.

Next, a physical therapist or physical therapy assistant performed a manual strength examination using a hand-held dynamometer (Empi Microfet2, St. Paul, MN). All muscle groups were tested in gravity-eliminated positions. The postures, placement of the dynamometer, and stabilization points were standardized (see Table 2 in Appendix II). The verbal encouragement used for each test was also standardized. For each test, the subject pushed against the padded dynamometer force plate which the physical therapist was holding stationary. The subject was asked to slowly build to a maximal force and then hold this maximal effort for 4-5 seconds. There was a minimum of two trials for each muscle group. Additional measurements were taken only if the first two trials varied by more than 10% or by more than 1 lb. for strengths less than 10 lbs. The maximum number of trials for a single muscle group

was four to prevent fatigue. For each subject, those muscle groups which did not have two trials which met the 10% or 1 lb. criteria after four attempts were excluded from the analysis. In addition, if a subject reported pain during testing, those trials were considered invalid and excluded from the data analysis.

The digital hand-held dynamometer measured the peak force and had a range of 0 to 100 lbs. The accuracy of the dynamometers used in this study was checked by vertically loading certified weights on their end pieces.

Once the dynamometer testing was completed, the physical therapist performed manual muscle testing using a standardized protocol on selected muscle groups. Eligibility for the treatment studies depended on these manual muscle strength levels. The selected muscle groups were the shoulder flexors and abductors, elbow flexors and extensors, knee flexors and extensors, hip extensors and abductors, and ankle plantar flexors. Each test was done in a gravity-resistant posture and the Lovett grading system was used. If the grade was equal to or greater than 3, it was specified using (+) or (-) signs to distinguish between levels. Otherwise, a muscle grade of <3 was recorded.

Reliability

Sixteen polio survivors underwent symptom assessments by the two nurses involved in the study. These results were used to determine symptom interrater reliability. A period of one to five days separated the two assessments for each subject. All assessments were done at the same time of day.

In order to determine the interrater reliability of the strength measurements, six subjects (2 polio survivors and 4 individuals with no history of polio or other neuromuscular disorders) had their strength measured by each of the three physical therapists involved in data collection for this study. For each subject, all strength assessments were performed at the same time of day within a one-month period.

Additionally, 10 polio underwent additional strength testing with the Kinetic Communicator Exercise System (KINCOM) as a reliability check for the hand-held dynamometer. Isometric strength

was measured in the knee flexors and extensors and the elbow flexors and extensors. All subjects involved in this testing were required to have grade 3 or better strength in each of the selected mucle groups.

RESULTS AND DISCUSSION

Reliability

In order to determine strength reliability, we calculated interrater correlation coefficients [ICC(3,1)].[24] These results are summarized in Table 3 in Appendix II. Reliability was very high for most muscle groups (above 0.8). All muscle groups had coefficients over 0.7 except for neck extension and ankle plantar flexion. Neck extension strength was difficult to measure reliably because of the awkward positioning required. The ankle plantar flexors were one of the strongest muscle groups measured and as a result, the examiners occasionally experienced some problems with stabilization and positioning.

For symptomatology interrater reliability, we calculated p_o or the proportion of observed agreement (see Table 4 in Appendix II). Once again, reliability was good with all symptom/deformity tests having values for p_o of 0.8 or higher, with the exception of scoliosis and patella-femoral crepitation. For the most part, both of these tests relied on the examiner's subjective opinion. Therefore, some of the discrepancies may have been due to the difference in experience level for the two nurses. The nurse who did the majority of the symptom testing worked for the orthopedic department and had several years of experience in doing similar exams. The other nurse was an experienced rehabilitation nurse, however she did not have any experience in orthopedic examinations prior to the training she received for this project.

For the dynamometer reliability, we compared the mean strengths obtained from the hand-held dynamometer to those obtained from the Kin-Com dynamometer (summarized in Table 5 in Appendix

II). None of the means were significantly different from one another, except for knee extension on the right side. The mean strength obtained with the hand-held dynamometer for this muscle group was lower than that obtained with the Kin-Com.

Subject Characteristics

Descriptive characteristics of the study population are summarized in Table 6 in Appendix II. The range in age was 32 to 81 years. The median age at onset of polio was 5 years, and the median number of years since polio was 48, ranging from 29 to 80 years.

Each subject was asked to identify the sites where they had residual weakness or paralysis immediately following the original polio infection. The possible sites included neck, back, abdomen, left arm, right arm, left leg, and right leg. The highest percentages were seen for the legs (57% for left leg and 55% for right leg). All of the remaining sites had values below 25%. Approximately 7% of the subjects stated that they were left with no noticeable weakness or paralysis after recovering from the original polio infection.

When study participants were asked to identify any new muscle problems they may have been experiencing recently: 70% cited increasing weakness, 54% cited increasing muscle pain, 47% cited an increasing occurrence of muscle cramps, and 40% cited increased muscle twitching. When asked to specify which activities seemed to bring on or aggravate these problems, the most common responses were: walking (25%), standing (14%), lifting (6%), exercising (5%) and climbing stairs (5%).

Symptom Prevalence

Table 7 in Appendix II gives the percentage of positive responses given for each symptom/deformity test. For deformities, the highest percentages of subjects were seen for cavus feet (40-41%) and scoliosis (41%). For symptoms, the highest percentages of subjects were seen for biceps

palpation (10%), supraspinatus (impingment) test (12-16%) , numbness or tingling of the hand/wrist (17-20%), plantar fascia tenderness (10%), and patella-femoral crepitation without pain (39-41%).

Prediction Models

Because of the tremendous number of variables involved, we developed several *a priori* prediction models in order to reduce the risk of Type I error. These prediction models were based on previous findings in the literature and theories of movement compensation. Each model identified a potentially problematic muscle or group of muscles and then based on weakness in that muscle(s), predicted the overuse problems which might result. A total of seven models were developed. However, we were unable to perform any data analysis for two of these models due to the small number of subjects who had the required symptoms. The other five models are described in the following sections. Each section gives a description of a prediction model or apriori hypothesis and then summarizes the results of the analysis pertaining to that particular hypothesis. For all analyses, statistical significance was defined as $p \leq 0.05$.

Model #1: Weakness of calf muscles will result in knee crepitation and/or pain.

Hypothesis: Weakness of the gastrocnemius and soleus muscles will result in increased muscular demand on the quadriceps muscle. The gastrocnemius and soleus muscles stabilize the tibia from mid-stance to terminal stance. During ambulation, as the tibia rotates forward in the stance phase, the weakened gastrocnemius and soleus muscles may be unable to control the flexion tendency at the knee. The quadriceps will then become active and will be used to keep the knee extended so that it doesn't buckle as the body weight (i.e. center of gravity) moves forward over the foot. The usual activation pattern for the quadriceps muscle is for a very short period of time in the last swing and early stance phases. With the increased demand on the quadriceps, they become active for a much longer

period of time. This is the theoretical etiology of knee pain with patellar tendinitis and patella-femoral crepitation or arthritis. The patella is the fulcrum of the quadriceps muscle. This model would apply only to ambulators.

Analysis and Results: Among the 194 polio subjects enrolled in the study, there were a total of 185 ambulators. Based on clinical experience and our knowledge of biomechanics, we hypothesized that the subjects at highest risk for knee pain or crepitation would have a minimum of gravity-resistant strength (grade 3) in their knee extensors in order to allow for possible compensation for weak calf muscles. We also hypothesized that subjects who do not wear articulating braces with a dorsiflexion stop would be at higher risk for knee symptoms than those who do wear braces. These braces are designed to supplement the weak calf musculature and should make the development of knee symptoms less likely.

Since strength and brace use could vary from leg to leg on the same person, thereby putting each leg at a different level of risk for symptoms, separate analyses were performed for the dominant and non-dominant sides. Dominance was established for each subject by asking which leg would he/she use to kick a ball or when walking which leg steps first. Within each side, legs were grouped based on whether or not an articulating brace with dorsiflexion stop was worn (Yes/No), whether or not knee extensor strength was grade 3 or better (Yes/No), and whether or not the knee had symptoms when assessed (Yes/No).

The mean ankle plantar flexor strength was compared between the symptomatic and asymptomatic groups for patella-femoral crepitation with or without knee pain. A separate analysis was run for only legs with knee pain. The results are summarized in Tables 8 and 9 in Appendix II.

There were 7 subjects who had unilateral knee pain. The mean ankle plantar flexor strength in the legs with knee pain was compared to the mean strength in the asymptomatic legs. Although the

symptomatic legs were weaker (22.46 lb.) than the asymptomatic legs (37.71 lb.), the difference was not significant (Wilcoxon p-value = 0.4688).

Discussion: We predicted that legs with patella-femoral creptitation with or without knee pain would have significantly weaker ankle plantar flexors than legs without knee symptoms. However, our results showed that while the mean ankle plantar flexor strength for the symptomatic legs for both knee pain and crepitation tended to be smaller than the mean strength for the asymptomatic legs, these differences were not significant. The only exception was for legs with weak quadriceps and no braces. Within this subgroup, legs with patella-femoral crepitation were significantly weaker than legs with no knee symptoms on the dominant side only.

We had also predicted that legs with strong quadriceps and no brace, combined with ankle plantar flexor weakness, would be at highest risk for developing symptoms. However, our results showed that the percentage of subjects with patella-femoral crepitation in this group (42% for the dominant side and 44% for the non-dominant side) was not significantly different than the percentages seen in the other three groups (varied from 40% to 47% for the dominant side and from 25% to 65% on the non-dominant side).

In the between-subjects comparison, the value for mean ankle plantar flexor strength was lower for subjects who had knee pain compared to those who did not in the group predicted to be at highest risk (no braces and strong quadriceps) for both the dominant and non-dominant sides. While these differences were much higher than those seen for any of the other groups, they still were not statistically significant. The results of the within-subjects comparision yielded similar results. While the mean ankle plantar flexor strength in the legs with knee pain was smaller than that in the legs without knee pain, the difference was not statistically significant.

Overall, there appears to be some support for our hypothesis. We did not see the strength differences we expected for patella-femoral crepitation, however these differences did become more

apparent when we looked at knee pain. One of the mitigating factors which must be considered is the relatively small number of subjects included in the groups with braces and/or weak quadriceps, and also the very small number of subjects who had knee pain.

Model #2: Weakness in the leg extensor muscles will lead to shoulder overuse symptoms.

Hypothesis: Average weakness of the hip and knee extensor muscles in the lower extremities causes individuals to lean heavily on their arms when rising from a seated position (assuming moderate to strong arms). This is the theoretical etiology of supraspinatus and biceps weakness, tendinitis, and rotator cuff pathology. Increased impairment of the lower extremities is a common complaint among polio survivors. Often, this impairment may be the result of hip extensor and/or knee extensor weakness. Previous studies have documented that these "anti-gravity" muscles had a lower recovery rate compared to flexor muscles.[25] We predicted the individuals with moderate levels of weakness in their hip extensor and/or knee extensor muscles would use their arms to help compensate during stabilization and mobility tasks (e.g. rising from a chair), as opposed to someone with normal levels of leg extensor strength who would not need to use their arms to perform the same tasks.

Analysis and Results: A combination of palpation and resistance tests of the biceps and supraspinatus were used to look for areas of pain or tenderness in each shoulder. Overall, 90 (50%) of the subjects in this study had one or more shoulder symptoms.

In order to determine whether certain shoulder symptoms tended to be linked in their occurence either by structure (biceps vs. supraspinatus) or type of test (palpation vs. resistance test), a correspondence analysis was performed. Subjects were classified based on the presence or absence of each shoulder symptom. The results of this analysis showed that there were two distinct clusters (displayed in Figure 3 in Appendix I). Cluster 1 consisted of the four palpation tests (left and right biceps palpation and left and right supraspinatus palpation). Cluster 2 consisted of the four resistance

tests (left and right supraspinatus (impingment) tests and left and right biceps tests). Replication of the analysis for each gender separately gave similar results. There was no significant association between clusters (Chi-square value = 0.060, 1d.f., p - 0.806). Overall, 30 (17%) subjects had symptoms in Cluster 1 (palpation symptoms) only, 43 (24%) subjects had Cluster 2 (resistance symptoms) only, and 17 (9%) subjects had symptoms in both clusters.

Examination of the breakdown between males and females within each symptom cluster revealed a significant association between gender and the presence of palpation symptoms (Chi-square value = 15.552, 1.d.f., p-value < 0.001). A total of 38 (42%) females had palpation symptoms compared to only 9 (10%) males. However, the breakdown by gender for the resistance symptoms was approximately equal with 31 (34%) females and 29 (33%) males.

Because of the small number of males with palpation symptoms, we limited our analysis of these symptoms to females only. The potential predictor variables were age, time since polio, weight, height, the combined strength of both knee extensors (KNEES), the combined strength of both hip extensors (HIPS), the combined strength of both knee extensors and both hip extensors (ALL), the combined strength of both shoulder abductors (ABDS), the combined strength of both shoulder flexors (FLEX), and lower limb, upper limb, and transfer activity scores.

Strength values were broken down into bins with approximately equal frequencies (quintiles). The percentage of subjects in each quintile who had specific symptoms was calculated in order to determine, on a preliminary basis, the nature of the relationship between strength and symptoms. A similar analysis was performed for the other independent variables.

Plots of the percentage of subjects with shoulder symptoms against the strength of each muscle group (in quintiles) revealed neither a linear pattern nor a good fit to a polynomial equation. Similar patterns were seen for the other independent variables identified as potential predictors. Therefore, each of these potential predictors were defined as categorical variables with quintiles as levels. The only

exception was weight. In the plot of the proportion of subjects with palpation symptoms versus weight, we observed an increasing pattern. Therefore, this variable was treated as quantitative instead of categorical.

Each predictor variable was entered into a univariate logistic regression model with presence or absence of palpation symptoms as the dependent variable. The results of the univariate analysis showed that weight, age, KNEES, ALL, FLEX, and upper limb activity score had p-values less than or equal to the pre-determined cutoff of 0.15. These variables were entered into a stepwise multivariate logistic regression model. The results of the multivariate analysis showed that the model with KNEES and weight was the best predictor of palpation symptoms in this population.

The plot of the percentage of females with palpation symptoms versus overall knee extensor strength (in quintiles) showed evidence of a threshold effect as illustrated in Figure 4 in Appendix I. Females whose combined knee extensor strength was less than 79 lb. were at much higher risk for having palpation symptoms than those whose combined knee extensor strength was equal to or greater than 79 lb. Figure 5 in Appendix I is a plot of the proportion of females with palpation symptoms versus weight (in quintiles). As weight increased, the proportion of females with shoulder symptoms also increased. Females who weighed more than 154 lb. were at much higher risk than those who weighed less.

The analysis for the resistance symptoms was similar to that for the palpation symptoms except that both males and females were included. The potential predictor variables were the same. Since a Chi-square analysis showed no significant association between gender and the presence of resistance symptoms (Chi-square value = 0.025, p = 0.999), we initially performed the logistic analysis with both genders combined.

The outcome of the univariate analysis included HIPS, KNEES, ALL, and age. The results of the multivariate analysis showed that the model containing ALL and age was the best predictor of resistance symptoms. Figure 6 in Appendix I illustrates the plot of the proportion of subjects with

resistance symptoms versus ALL in quintiles. The graph shows that the highest proportion of subjects with symptoms was found in the mid-range for leg extensor strength. A plot of the proportion of subjects with resistance symptoms versus age in quintiles is displayed in Figure 7 in Appendix I. Subjects who were between 50 and 54 years of age were at highest risk for developing these symptoms.

Despite the fact that we found no significant gender effect for resistance symptoms, there was some concern about whether gender was possibly confounding our results. In the literature, there are well-documented gender differences in muscle strength and body size. Therefore, we decided to analyze males and females separately in order to determine if the relationship between resistance symptoms and the potential predictor variables was the same for both genders.

The results of the univariate analysis for males showed that KNEES and age were the only variables which met the cutoff criteria. The stepwise multivariate analysis resulted in a model containing both variables with the highest proportion of males with symptoms in the mid-range for knee extensor strength and age. For females, the results of the univariate analysis included HIPS, ALL, and age, and the multivariate analysis produced a model containing HIPS and age. The females with the highest proportion of symptoms had the weakest hip extensors, followed closely by those with mid-range strength. In terms of age, females in the lower quintiles had the highest proportion of symptoms.

A comparison of the KNEES model and the HIPS model for both genders is displayed in Table 10 in Appendix II. The odds ratios represent the level of risk for each quintile compared to quintile 5 which contained the strongest subjects. An odds ratio equal to one would mean the level of risk was about the same compared to quintile 5. For males, the KNEES model appears stronger than the HIPS model with larger, more significant odds ratios and a higher sensitivity value. However, the HIPS model for males has a higher value for specificity than the KNEES model. For females, the odds ratios for both the knee and hip models show similar patterns, and the sensitivity and specificity values for both models are comparable.

Discussion: The purpose of this model was to determine if there was a systematic relationship between the presence and location of lower extremity weakness and the presence of pain potentially attributable to shoulder overuse. We predicted that the percentage of subjects with shoulder symptoms would be highest in the mid-range of leg extensor strength since these individuals would be more active than those with severe weakness and would put more stress on their arms than those with mild or no noticeable weakness.

Our results showed that the shoulder symptoms could be broken down into two distinct symptom clusters based on the type of testing used for assessment. The results of the multivariate analyses appear to support the theory that these are two different symptom complexes. The palpation symptoms may be more closely associated with tendinitis or other similar conditions characterized by inflammation and tenderness to the touch. The resistance symptoms are probably more closely related to impingement problems which are characterized by pain with active motion.

Our results also showed that palpation symptoms were more common among females, as are many overuse injuries.[26,27] This may be due to differences in pain perception and report. Previous studies have suggested that men have a higher pain tolerance than women, especially in tests involving pressure pain.[28,29,30]

In order to determine if gender differences might simply be related to greater stoicism among men, we assessed the severity ratings for the resistance symptoms. We found no significant difference; women did not rate their pain intensity higher than men.

Our results showed that palpation symptoms among women were strongly related to knee extensor strength and weight. The most likely explanation is that weak knee extensors cause increased demand on the arms during tasks such as getting up from a chair or using an assistive device for ambulation. Increased weight will also result in an increased demand on the arms during similar tasks. Unfortunately, we did not have sufficient power to allow us to distinguish a threshold model from the

predicted curvilinear model. From the graph of proportion of females with palpation symptoms versus quintiles of knee extensor strength, it did appear that the proportion was highest in the mid-range for strength. However, it was not possible to detemine whether subjects with moderate weakness were truly at higher risk than profoundly weak subjects or whether this peak was simply due to random error.

In terms of predicting resistance symptoms, we were not able to draw any definitive conclusions in terms of which aspect of lower extremity strength was the best predictor. While it did appear that some aspect of lower extremity strength is a significant predictor for resistance symptoms for both genders, the results were variable between KNEES, HIPS, and ALL, depending on which genders were included in the regression model. The results for males suggest that knee extensor strength is more important. However, for females the results were not as clear, and there remains some doubt as to whether hip extensor or knee extensor strength is the best predictor for females.

One explanation for the possible difference between genders is that resistance symptoms are actually a more complicated phenomenon in females, possibly related to gender differences in anatomy (e.g. females on average have wider hips than males). These anatomical differences may result in different compensation patterns when muscle weakness is present. However, it is also possible that the effect of knee extensor strength for females was obscured by random error or noise in the data, and the compensatory mechanisms are the same.

Since age was an important factor for resistance symptoms and not for palpation symptoms, we theorized that resistance symptoms may actually be a late manifestation of repeated episodes of palpation symptoms. In other words, shoulders which have suffered from recurrent bouts of tendinitis may eventually begin to degenerate resulting in impingement-related problems. A comparison of females with palpation symptoms versus females with resistance symptoms showed a slightly higher mean age for those with resistance symptoms. However, the difference was not significant (59.4 years vs. 57.2 years). This provides somewhat weak support for this hypothesis, but the fact that both palpation and

resistance symptoms are more common in the lower age quintiles would seem to contradict it. More research is needed into the role that age plays in the development of resistance symptoms and the relationship between the two symptom clusters.

One of the limitations of this study was that we did not have the power to test interactions between independent variables due to the relatively low percentage of subjects with each symptom cluster. More data are needed in order to capture the complicated synergisms which may exist between variables. For example, we would expect that there would be an interaction between strength and weight. Previous studies have documented that the amount of muscle strength required to perform daily activities increases as weight increases.[31,32,33] Weight was an important predictor for palpation symptoms along with overall knee extensor strength. We attempted to capture the interaction between knee strength and weight by calculating the ratio between the two variables (knee extensor strength divided by weight). However, our analysis showed that this ratio was not significant at the univariate level.

Model #3: A foot with a high arch (cavus deformity) will be at high risk for plantar fasciitis.

Hypothesis: A cavus deformity which is characterized by a high arch is caused by an imbalance in the strength of the muscles of the feet (i.e. toe flexor strength is greater than toe extensor strength). A cavus deformity of the foot places increased strain on the plantar fascia during standing and walking. This is the theoretical etiology of plantar fascia tenderness and metatarsalgia. This model would apply to ambulators who do not use crutches or braces with a molded foot plate and/or dorsi-stop. A brace with a foot plate or a dorsiflexion stop provides external support to the foot and should result in a lower risk for development of plantar fascia tenderness.

Analysis and Results: A total of 105 subjects or 54% of our study population had a cavus deformity in one or both feet (50 males and 55 females). Approximately 26% (27 out of 105) of these

subjects had plantar fascia tenderness in the foot with the cavus deformity, as compared to 21% (19 out of 89) of the subjects without cavus in either foot who had plantar fascia tenderness in one or both feet. Overall, there was not a statistically significant association between the presence of a cavus deformity and plantar fascia tenderness (Chi-square value = 0.817, 1 d.f., p = 0.366).

Of the 27 subjects (16 females and 11 males) with cavus and plantar fascia tenderness in the same foot or in both feet, all were ambulators. Approximately 50% (13 out of 27) wore braces with a molded foot plate on the side with cavus and the plantar fascia tenderness. In addition, approximately 50% (13 out of 27) used an assistive device for ambulation (12 used a cane, 3 used crutches, and 2 used a wheelchair for long distances).

There were 11 subjects who had unilateral cavus and unilateral plantar fascia tenderness. In terms of which side was more likely to have plantar fascia tenderness, the likelihood appeared almost equal for either side. Six of these subjects had symptoms on the cavus side and five subjects had symptoms on the non-cavus (normal arch) side.

A within-subjects comparison of severity ratings for plantar fascia tenderness on feet with cavus and without in subjects with unilateral cavus showed that only approximately half of the sample (10 out of 19) were in the expected direction or had more severe pain on the side with cavus. Once again, there was no significant association between plantar fascia tenderness and cavus (Wilcoxon p-value = 0.968). Mean severity ratings for both groups were nearly equivalent (mean VAS = 33.0 for feet with cavus; mean VAS = 32.8 for feet without cavus). Among the five subjects who had bilateral plantar fascia tenderness and unilateral cavus, the mean severity rating was actually higher for the feet without cavus (mean VAS = 64) compared to the feet with cavus (mean VAS = 59).

Another hypothesis was that people with higher weights would be at higher risk for developing plantar fascia tenderness because the increased stress on the feet during walking. However, there we

found no significant difference in the mean weight of subjects with plantar fascia tenderness compared to subjects without plantar fascia tenderness (Mann-Whitney U test statistic = 3700.5, p = 0.496).

Discussion: Overall, our findings do not provide evidence to support our hypothesis. While the proportion of ambulatory subjects with plantar fascia tenderness was slightly higher for those with cavus versus those without, the difference was not significant. Among the subjects who had unilateral cavus and unilateral plantar fascia tenderness, the proportion of people with both cavus and tenderness in the same foot (6 out of 11) was almost equivalent to the proportion of people who had cavus on one side and tenderness on the other side (5 out of 11). There was also no evidence to show that plantar fascia tenderness in feet with cavus was more severe than in feet without cavus or that the risk for developing plantar fascia tenderness was lower in individuals who wear braces or use assistive devices for ambulation compared to those who do not.

Model #4: Use of crutches, walkers, or other upper extremity aides for ambulation is associated with carpal tunnel syndrome.

Hypothesis: Previous studies have documented that a large proportion of polio survivors who use ambulatory aides, such as canes, crutches, and walkers, have symptoms of carpal tunnel syndrome.[34] These symptoms may also result from pushing up from a wheelchair, as seen when doing transfers. Leaning on the hand repetitively can cause direct compression of the median nerve. It can also cause swelling of the tendons within the carpal canal which will put pressure on the median nerve, since the carpal canal has a finite volume. In addition, the tendons and the nerve can become inflamed when an individual must tightly grasp a cane or crutch. The tension created by the tendons constantly contracting with the wrist in hyperextension, pushes the median nerve upwards against the transverse carpal ligament. When the nerve is compressed, the result is feelings of numbness, tingling, and/or pain in the

hand, wrist, or arm. Therefore, we predicted that there would be a significnat association between the use of ambulatory aides and symptoms of carpal tunnel syndrome within our study population.

Analysis and Results: Among the 194 polio survivors enrolled in this study, approximately 40% or 78 people used one or more assistive devices on a regular basis. Looking at the breakdown by device: 26% used a cane, 15% used crutches, 13% used a wheelchair, 10% used a scooter, and 8% used a walker.

The tests used to evaluate the symptoms of carpal tunnel syndrome (CTS) were Phalen's test and Tinel's test. Subjects were also asked if they experienced numbness or tingling sensations in their hands/arms and were checked for signs of thenar atrophy. The total number of possible symptoms was four on each side or eight total. Approximately 53% (103 out of 194) of the subjects had one or more symptoms or signs of CTS.

Subjects were separated into groups based on use or non-use of assistive devices and presence or absence of any CTS symptoms or signs. Our analysis showed that the association between use of assistive devices and presence of CTS symptoms/signs was marginally significant (Chi-square value = 3.736, 1 d.f., $p = 0.053$). This analysis was repeated for each of the four symptom/sign tests separately. Once again, the results showed that assistive device users were more likely to have CTS symptoms than non-users. However, the only analysis which showed a significant association between device use and symptoms was for the presence of thenar atrophy (Chi-square value = 4.000, 1 d.f., $p = 0.046$).

There was a significant difference between assistive device users and non-users in the number of CTS symptoms/signs per subject (Mann-Whitney U test statistic = 3557.5, $p = 0.007$). The non-user group was more likely to have no symptoms or one symptom/sign compared to the device user group, which was more likely to have two or more symptoms/signs. Device users were also almost twice as likely to have bilateral symptoms/signs compared to non-users (29% vs. 16%).

When separate analyses were done for each device, the results showed a significant association between wheelchair use and presence of CTS symptoms (Chi-square value = 6.047, 1 d.f., p = 0.014). The association between scooter use and presence of CTS symptoms was marginally significant (Chi-square value = 3.586, 1 d.f., p = 0.058). Our analysis showed no significant association between cane, crutch, or walker use and CTS symptoms.

Discussion: Our analysis provided support for our hypothesis and confirms the results documented in previously published studies. Overall, assistive device users did have more symptoms/signs of CTS than non-users and were more likely to have bilateral symptoms. There was also a strong association between wheelchair and scooter use and the development of CTS symptoms. People who use these devices tend to have significant levels of weakness in their leg muscles. As the legs become weaker, the demand increases on the arms (e.g. during transfers). This will increase the probability for development of symptoms related to overuse in the wrists, elbows, and shoulders.

Model #5: Hip abductor weakness will lead to tenderness at the greater trochanter.

Hypothesis: Ipsilateral hip abductor weakness will result in hip tendinitis. The hip abductor muscles (gluteus medius and gluteus minimus) are used to stabilize the pelvis during the stance phase of gait to provide single limb support on the ipsilateral limb. If these muscles are weak, they must expend maximum effort for longer periods of time than normal. If the strength of these muscles is insufficient to control the trunk posture over the stance limb, the result is stretching of the hip abductor musculature at its tendons at their attachment to the greater trochanter. This may then result in greater trochantic bursitis/tendinitis. One of the symptoms of this overuse injury is tenderness to palpation over the greater trochanter. We predicted that there would be a significant association between hip abductor weakness and greater trochanter tenderness. We also predicted that ambulators who do not use crutches would be at highest risk for development of symptoms.

Analysis and Results Separate analyses were performed for the dominant and non-dominant sides, and subjects were divided into groups based on whether or not they had hip pain. A total of 31 ambulators had greater trochanter tenderness or hip pain on one or both sides. None of these subjects were crutch users. We compared the mean hip abductor strength of the symptomatic subjects versus the asymptomatic subjects. The results are summarized in Table 11 in Appendix II. There was a significant difference in strength between groups on both the dominant and non-dominant sides. As predicted, the hips with pain were significantly weaker than the hips without pain.

There were 17 subjects with unilateral hip pain and valid strength values for both hip abductors. We compared the mean hip abductor strength of the hips with pain versus those without pain among these subjects. The within-subjects comparison revealed no significant difference in mean strength between the two sides (Wilcoxon p-value = 0.379). In fact, the mean hip abductor strength for the hips with pain (20.150 lb.) was slightly larger than the mean strength for the hips without pain (18.644 lb.). However, 11 out of 17 subjects had results in the predicted direction (i.e. a lower value for hip abductor strength on the side with hip pain versus the side without).

In addition, there were 10 subjects with bilateral hip pain and valid strength results for both hip abductors. For each subject, we compared their hip abductor strength from both sides and designated the one with the largest strength value as the strong hip and the remaining hip as the weak hip. Then, we compared the mean severity ratings for both group. The result of the within-subjects comparison was marginally-significant (Wilcoxon p-value = 0.059) with the weaker side having a higher mean severity rating (mean VAS = 43.1) than the stronger side (mean VAS = 24.9).

Discussion: The analysis for this model seems to provide some support for our hypothesis. The between-subjects comparison of the mean hip abductor strength for hips with pain versus those without pain showed that hips with pain were significantly weaker than those without pain, and while the within-subjects comparison of mean hip abductor strength for those subjects with unilateral hip pain showed no

significant difference in mean strength between hips, the majority of subjects (65%) had results in the predicted direction. In addition, the comparison of severity ratings for those subjects with bilateral hip pain, showed that the mean severity rating was higher on the weaker side.

STUDY #2: LONGITUDINAL STUDY OF THE DEVELOPMENT OF NEW OVERUSE SYMPTOMS IN POST-POLIO SURVIVORS

RATIONALE:

From the cross-sectional study, it will not be possible to determine with certainty whether weakness leads to overuse symptoms, or whether overuse symptoms lead to weakness (through reduced activity of the affected limb). In order to clarify the direction of causation, strength data gathered at one clinic visit will be used to predict onset of new overuse symptoms at subsequent visits.

OBJECTIVES:

1) to determine the incidence of new soft tissue muscle overuse problems;

2) to determine the continued prevalence of those soft tissue overuse disorders detected in the initial screening; and

3) to clarify the causal sequence of the weakness--overuse--injury cycle.

METHOD

Subjects:

All 194 subjects from the initial cohort (study #1) were enrolled in this study. However, 74 subjects were lost to follow-up for one reason or another. A total of 120 polio subjects completed all required visits within the specified time period. Informed consent was obtained for all subjects.

Procedure:

The subjects underwent a standard Research Clinic evaluation, as described in Study #1, three times at approximately 3-5 month intervals.

ANALYSIS AND RESULTS

After reviewing the symptom data, it became apparent that we could not reliably predict the onset of new overuse symptoms using the strength data from a subsequent visit. A survival analysis was performed to determine the continued prevalence of overuse symptoms detected in the initial screening. The results showed that only a small percentage of subjects who complained of a specific symptom in the initial visit, consistently reported this symptom for the remaining two visits. However, we felt that it was important to establish whether or not there was a significant change in strength over time among the polio survivors and if so, which muscle groups were involved.

In order to determine if there was a significant change in overall upper body and lower body strength , the data were analyzed using a repeated measures multivariate analysis of variance (MANOVA). There were 8 muscle groups included in the upper body analysis (shoulder flexors, extensors, abductors and external rotators; elbow flexors and extensors; and wrist flexors and extensors) and 7 muscle groups included in the lower body analysis (hip flexors, extensors, and abductors; knee flexors and extensors, and ankle plantar flexors and dorsiflexors). For each group, only subjects with valid readings for all muscle groups for all three visits could be included in the analysis. We also excluded any subjects whose initial strength for any of the muscle groups was equal to 0 lb. For the upper body, 26 subjects were excluded because they had pain during one or more of the strength trials and 17 subjects were excluded because of missing values and 6 were excluded because they had one or more muscles with an initial strength equal to zero, leaving a total of 71 subjects for analysis. For the lower body, 12 subjects were excluded because of pain during the strength assessment, 13 subjects were

excluded because of missing values, and 30 were excluded because their initial strength equaled zero for one or more muscle groups, leaving a total of 65 subjects for analysis.

Results for the Upper Body

Our analysis showed that there were significant differences ($p < 0.001$) in mean strength between the muscle groups (i.e. some muscle groups were stronger than others). The results also showed that overall there were no significant differences ($p > 0.05$) in mean strength between the left and right side. However, the interaction between muscle and side was significant ($p < 0.001$) indicating that the relationship between the left and right sides was not the same for individual muscles as shown in Figure 8 in Appendix I. Several of the muscle groups are stronger on the right compared to the left (e.g. wrist flexion and elbow extension) while other muscle groups show little or no difference between sides.

There was a significant change in mean strength over time. Since the interaction of muscle and time was also significant, this meant that the change in mean strength over time was different for different muscles as depicted in Figure 9 in Appendix I. While the strength of all the muscle groups appears to decline over the 6-9 month period between visit 1 and visit 3, the slopes of the lines are different indicating that some muscle groups are losing strength at a faster rate than others. In fact, the decrease in mean strength from visit 1 to visit 3 was significant for all muscle groups except shoulder flexors.

The interaction between time and side was not significant ($p > 0.05$) indicating the change in mean strength over time was similar for both left and right sides.

Results for the Lower Body

The results for the lower body are very similar to the upper body in terms of main effects and are illustrated in Figures 10 and 11 in Appendix I. Once again, the results showed a significant difference in

the mean strength between muscle groups and a significant change in mean strength over time. Unlike the muscles of the upper body which all showed a decline in strength over time, the muscles in the lower body group showed a variety of patterns. Several of the muscle groups showed no significant change in mean strength over the 6-9 month period including hip abduction, hip extension, and knee extension. Other muscle groups, including the ankle dorsiflexors, knee flexors, and hip flexors, showed a decline in mean strength over the same period. The ankle plantar flexors showed an increase in mean strength over time. However, this result is questionable based on the low interrater reliability discussed in an earlier section.

In terms of the interaction between muscle and side, the mean strength of the knee extensors and hip flexors was larger on the right side than the left side. The remaining muscle groups showed the opposite pattern with the larger mean strengths on the left side.

DISCUSSION

Most of the studies which have looked at longitudinal changes in strength over time among polio survivors have focused their analysis on only one or two muscle groups.[35,36,37,38] Most often, the quadricep or knee extensor is chosen because it is easily isolated for testing, the test-retest reliability is generally high, and there are many other studies which involve this muscle group to refer to for comparison. The results from these studies are contradictory and leave some question as to whether polio survivors are losing strength at an accelerated rate compared to the general population and if so, which muscle groups are involved.

In addition, most (if not all) of these studies required their subjects to have strength equal to grade 3+ or greater in the muscle being tested (i.e. gravity-resistant strength). The reason was that the investigators felt that it would be too difficult to detect changes in strength in muscles with less than "good" or "normal" strength initially.

In the current study, we included individuals with all levels of strength, except for those whose initial strength was zero. We looked at the changes in mean strength for muscle groups in both the upper and lower body. Although our study only covered a period of 6-9 months, we still found evidence of decreasing strength over time. However, the muscle groups which were considered most likely to show a decrease in strength (i.e. the "weight-bearing" or "gravity-resistant" muscles like the knee extensors) were not the ones where we found significant changes. Instead, our results showed a decrease in mean strength for most of the muscles of the upper body and also for the flexor muscles in the lower body. This has interesting implications for treatment programs designed to help polio survivors conserve or improve their existing muscle strength to help them maintain their independence for as long as possible.

STUDY #3: PATTERNS OF MUSCLE SUBSTITUTION USED TO COMPENSATE FOR FOCAL WEAKNESS IN SURVIVIORS OF POLIO AND INDIVIDUALS WITH RECENT MUSCULOSKELETAL SURGERY

RATIONALE

Since many of the overuse symptoms in polio survivors occur in strong muscles used to compensate for weak ones, it is necessary to understand the biomechanical strategies used in compensation in order to predict fully the location of overuse symptoms. The study of a common task in the presence of localized weakness should help clarify the patterns of compensation used.

OBJECTIVES

1) to determine the compensatory substitution patterns for knee weakness

2) to determine the biomechanical characteristics that will predict overuse sites.

METHOD

Subjects:

From the Research Clinic cohort, 15 polio subjects were selected for participation in this study. All subjects had predominant unilateral weakness of the knee extensors (defined as having a minimum of one MMT grade difference between sides). Potential subjects were identified using the MMT results from study #1. In addition, 7 control subjects who had unilateral knee surgery within the previous 4 - 8 weeks were recruited from the orthopedic practices of the Albert Einstein Medical Center. Surgery patients were required to have a minimum of a 10 lb. difference in knee extensor strength between the side which had recent surgery and the unaffected side. Thus, comparison groups with weakness in the same muscle groups from different etiologies were identified. Additional criteria used in subject selection was as follows:

1) subjects could not have any major disabilities unrelated to their polio or recent surgery that could affect the pattern of muscle use during the research task (e.g. acute back pain, peripheral neuropathy, diabetes, amputation, stroke, cancer, inflammatory arthritis, muscular dystrophy)
2) subjects must be able to stand up from a chair safely

Procedure:

Surgery patients underwent a screening evaluation during which their knee extensor strength was measured using the hand-held dynamometer, following the same protocol as for study #1.

Prior to any testing, subjects were issued the following standard precautions: not to overexert prior to the session, not to use creme or lotion on legs/arms, to bring shorts and a t-shirt or half-sleeve shirt. Subjects were familiarized with the protocol and implications. Informed consent and permission

to videotape was obtained. Anthropometric parameters of both lower and upper extremities was measured using calipers and measuring tape. Subjects were then weighed on a standard scale.

Surface electrodes were placed over the following muscles on both sides: tibialis anterior, soleus, vastus lateralis, rectus femoris, long head of biceps femoris, gluteus maximus, triceps, anterior aspect of the deltoid, and posterior aspect of the deltoid. Prior to electrode placement, the skin was cleaned and abraded with prep pads.

Selspot kinematic markers (light emitting diodes or LEDS) were placed in a standard configuration over various anatomical landmarks for measurement of body motion during the sit-to-stand performance. Twenty-four markers were used. Full body marker placement was as follows: a foot wand containing two LEDs, the base of which was positioned over the second metatarsal space of the foot. A marker was placed on the lateral malleolus, a wand on the midspan of the lateral aspect of the tibia, a marker on the estimate of the anatomical knee center, a wand on the midspan of the lateral aspect of the femur, a marker on the trochanter, and a rigid array of markers was placed over the posterior aspect of the pelvis. For the upper extremity, a trunk rigid array was supplemented with individual markers on the wrist, forearm, and upper arm. Data was sampled at 62.5 Hz. for kinematics and at 500 Hz. for electromyographic (EMG) activity. A video record was also taken to correlate quantitative differences in the pattern of motion.

The subjects performed a sit-to-stand (STS) task under four different sets of conditions. These conditions varied in terms of chair height and whether or not the subjects were allowed to use the armrests and were as follows:

a) Rising from a standard height chair (45.5 cm) without using arms

b) Rising from a standard height chair (45.5 cm) using arms

c) Rising from an elevated chair (55.5 cm) without using arms

d) Rising from an elevated chair (55.5 cm) using arms

The order in which these tests were performed was randomized. Each subject was encouraged to accomplish each task at their own pace. The chair rested on a platform which was positioned over a pair of extra large force plates which allowed natural placement of the foot on each force plate. In all conditions, subjects were told not to place their hands on the chair seat if they could perform the STS task without doing so. If, in conditions (a) and (c), the subjects were incapable of successful STS either by having their arms hang at their sides or by throwing their arms forward, they were allowed to place their hands on their thighs or knees to assist them. In conditions (b) and (d), subjects were asked to place their hands on the arm rests prior to beginnning the STS manuever. A pressure switch affixed to the seat was used to determine lift-off from the chair. The arms of the chair were instrumented with triaxial load cells in order to measure the forces placed upon them as the subject performed the STS.

In each condition, the subject performed the STS maneuver 4 to 8 times. Subjects were given time to rest, as needed, between trials and conditions.

PRELIMINARY ANALYSIS AND RESULTS

Matlab 5.0, Systat 7.0, and Microsoft Excel® are being used for data processing and analysis which is still underway. The dependent variables include muscle activity (EMG) data, arm support forces, ground support forces, and kinematic active marker data. In addition to analysis of these parameters, linear impulse, various segment velocities, and integrated EMG values are being calculated to enable characterization of the STS motion. Kinetic data is body weight normalized to enable comparisons between subjects.

Preliminary analysis has been done on relatively "global" parameters of the STS task. Results indicate that the kinetic demands for rising out of the chair are shifted from the weak extremity. There was several strategies employed by the subjects to accomplish this shifting, including simply changing body segments that are used to meet the force demands of the STS task (e.g. lower extremity to upper

extremity or weak side to strong side). Often times, this was accomplished by changing the position of one or more body segments, such as foot placement. Other strategies include more judicious use of inertial and momentum parameters, such as using increased forward velocity of the head-arms-trunk (HAT) segment to assist in overcoming demands of STS.

Current efforts in this area of analysis are geared toward categorizing the various compensation schemes observed and identifying trends according to test condition and specific subject parameters (e.g. muscle strength). This line of analysis has served to identify differences in strategies and verify the presence of compensation mechanisms. The next analysis will focus on biomechanical characteristics of the performance during the propulsion phase, categorizing how subjects met the changing demands and how these trends correlate to various subject and task parameters.

Continued analysis has resulted in the definition of rigorous, standard criteria for identification of the beginning and ending points for the propulsion phase of the STS task. This will allow for comparisons of peak and average values of EMG, kinetic, and kinematic parameters between conditions and between subjects during this phase of the STS task.

STUDY #4: INTERACTION BETWEEN AGE AND SEVERITY OF WEAKNESS IN DETERMINING THE ONSET OF OVERUSE SYMPTOMS IN POST-POLIO SURVIVORS

RATIONALE

Overuse syndromes can occur abruptly, based on sudden maximal exertion. More commonly, however, they occur over time as overused structures gradually succumb to repetitive forces. Thus, among post-polio survivors, the prevalence of overuse symptoms should increase with age and the age of onset should be inversely related to the severity of weakness.

OBJECTIVE

1) to determine if patients will greater weakness develop overuse injuries at a younger age

METHOD

Subjects

The full cohort of 194 polio subjects as described for study #1.

Procedure

This study rests on data gathered under the protocols of studies #1 and #2. Specifically, the strength, activity, and overuse symptom data from the first Research Clinic visit are being reanalyzed focusing on the effect of age.

PRELIMINARY ANALYSIS AND RESULTS

We did not have the power to test interactions between age and strength directly due to the relatively low percentage of subjects will each symptom. We are in the process of analyzing the data by breaking the population into groups based on age (e.g. young, middle, and old) and then comparing the mean strength for symptomatic and asymptomatic subjects in each group. A similar analysis will be done by first dividing the population into quintiles based on strength and comparing the mean age for subjects with symptoms versus those without. Overall, we would predict that subjects who have symptoms are weaker than those who do not, and that weaker subjects will develop symptoms at an earlier age compared to stronger subjects.

STUDY #5: DEVELOPMENT OF AGE-RELATED NORMS FOR CHANGES IN STRENGTH AND PREVALENCE OF SUBCLINICAL WEAKNESS AMONG ABLE-BODIED INDIVIDUALS

RATIONALE

In order to expand the PPS model of overuse syndromes to the able-bodied military and civilian populations, it is necessary to know the changes that occur in strength over the lifespan, and prevalence of subclinical focal weakness in the population at various ages. This would allow estimation of the susceptibility to overuse of individuals at different ages, and would set normative strength ranges in that context.

OBJECTIVES

1) to determine a "normal" curve for changes in strength and the changing prevalence of subclinical weakness with age, which may enable identification of individuals at risk for overuse injury at a young age (e.g. military recruits);
2) to determine how much variability in strength there is in the population at large at any given age.

METHOD

Subjects

A total of 226 able-bodied individuals (113 males and 113 females) were recruited from the community at large. The criteria used in subject selection was as follows:

1) no known history of polio or other diseases that might cause muscle weakness
   e.g. stroke, amputation, diabetes, peripheral neuropathy, inflammatory arthritis, muscular dystrophy

2) no unstable angina (chest pain due to heart disease that was not controlled by medicine)

3) no history of uncontrolled heart failure (heart failure that was not adequately controlled with medicine)

4) no severe breathing problems which required supplemental oxygen and could make it unsafe for subject to exert him/herself in a strength test.

Procedure

Each subject was seen once for a standard strength examination using the hand-held dynamometer (see study #1) and a brief screening interview for history of extremity injuries.

PRELIMINARY ANALYSIS AND RESULTS

The data analysis for this study is still in progress. Descriptive characteristics of the study population are summarized in Table 12 in Appendix II. The range in age was 18 to 88 years. Utilizing multiple regression procedures, we have developed prediction equations for each of the 31 muscle groups based on age, gender and body mass index (weight divided by height squared). By comparing the actual versus the expected strength values for each muscle group, we will determine the cutoff values for a 95% confidence interval. These cutoff values will then be used to determine what proportion of polio subjects have abnormal strength values.

We will also determine what proportion of controls have lower extremity strength that falls in the range that put polio survivors at high risk for shoulder symptoms. We will also look at whether we can predict the strength of the left muscle from the known strength of the right muscle, and if so, what the range of discrepancies is between left and right that might signify subclinical injury.

STUDY #6: A COMPARISON OF EXERCISE AND LIFESTYLE MODIFICATION, ALONE, AND IN COMBINATION, ON THE RESOLUTION OF OVERUSE SYMPTOMS IN A POST-POLIO POPULATION

RATIONALE

If it is the case that focal weakness predisposes to overuse syndromes, then resolution of those syndromes should be facilitated by either strengthening the relevant muscle groups or altering the behavioral patterns leading to overuse.

Using the prediction models from the cross-sectional study (#1) , we identified three possible scenarios for subject selection. Each scenario specified one or more muscle groups which we would focus on and the corresponding overuse symptoms. Scenario #1 involved weakness in the hip and knee extensors. According to the prediction model, individuals with weakness in these muscles will tend to use their arms more in order to compensate (especially when rising from a seated position). Therefore, we would expect to see an increased number of overuse symptoms in the shoulder. Scenario #2 focused on ankle plantar flexor weakness. People with weak calf muscles will tend to use their quadriceps or knee muscles more to compensate. Therefore, we would expect to see overuse symptoms in the knee. Finally, scenario #3 focused on hip abductor weakness. People with weak hip abductors are prone to developing hip tendinitis.

Originally, we decided that subjects who fell under any one of these scenarios would qualify for this study. However, due to the small number of subjects who qualified under two of the three scenarios, we decided to focus our analysis on scenario #1. Therefore, in this treatment study, we focused on subjects who had shoulder symptoms to see if an exercise program which focused on the hip extensor and/or knee extensor muscles or a lifestyle modification program which focused on how to avoid overusing the shoulders would reduce the number and/or the severity of the shoulder symptoms.

OBJECTIVE

1) to determine the efficacy of strengthening exercises and/or lifestyle modification on resolution of shoulder overuse symptoms and prevention of new overuse symptoms.

METHOD

Subjects

A subset of 29 polio survivors enrolled in the cross-sectional study (#1), who had symptoms of overuse in their shoulder(s) possibly related to the weakness in their leg extensor muscles were recruited for this study. To be eligible, the strength in their affected muscles had to be grade 3 or better to allow for effective strengthening. Six of these subjects did not complete the study due to job changes or personal problems (e.g. illness involving the himself or family member).

Procedure

The subjects were randomly assigned to one of three treatment groups. Group 1 was placed on a modified exercise program which focused on the hip extensor and/or knee extensor muscle groups. Group 2 was carefully instructed in lifestyle modification techniques to avoid overuse related to their lower extremity weakness. Group 3 received both treatment interventions.

Subjects were identified based on the data collected in study #1 and enrolled following informed consent. At their initial visit after randomization, each subject underwent a symptom assessment designed to quantify the severity of their shoulder symptoms. During this assessment, subjects performed three different motions which simulated motions needed for common everyday tasks. First, they were asked to place their hand on their head (a motion required to put on a hat or use a blow dryer). Next, they were asked to put their hand on their lower spine (a motion needed to tuck in a shirt). Finally, they were asked to put their hand in the air with the shoulder abducted 90° and the elbow flexed 90° (a

position often used when waving to another person). Each subject performed the three motions with the one hand and then repeated them with the other. If a subject experienced any shoulder pain while performing one of these motions, they were asked to rate the severity of the pain on a visual analog scale (similar to one used for study #1).

After all the motion testing was completed, the examiner performed a series of resistance tests. For the first test, the subject held an arm straight out at his/her side with the palm down. The examiner attempted to push the arm down while the subject resisted. A similar test was performed with the arm out straight in front. The last two tests were performed with the shoulder in neutral and the elbow flexed 90°. While the arm was in this position, the examiner attempted to internally rotate (push lower arm towards abdomen) or externally rotate (push lower arm out) while the subject resisted. Each of these tests were performed on both arms. Once again, if shoulder pain was experienced during any one of the tests, the subject rated the severity on a visual analog scale.

Depending on their assigned treatment group, subjects were then instructed in a home exercise program, a lifestyle modification program, or both. Although the specific exercises and lifestyle modifications were individually tailored, the principles of prescription were standardized across subjects. Instruction included an eductional videotape, individual consultation with a physical therapist, and printed material to take home. Each subject also received a 10 day supply of either acetaminaphen or ibuprophen. Subjects who were given an exercise program were given a log to fill out. Information in the log included days when exercises were performed and the number of sets and repetitions completed. Subjects were also asked to note if they experienced any discomfort or pain while performing the exercises. Subjects who did experience problems with the exercise program were told to call the Research Clinic and had their exercise programs modified as necessary.

Patients were seen in the Research Clinic on a monthly basis over a 3-4 month period (or a total of 4 visits). At each visit, subjects underwent a strength assessment (hip extensors and knee extensors

only), a shoulder symptom assessment, an interview regarding compliance with the prescribed regimen, and a "booster" educational session.

ANALYSIS AND RESULTS

Response to treatment or degree of symptom resolution was quantified in terms of change in the mean number of shoulder symptoms and change in the mean severity of the shoulder symptoms. For each subject, we used the sum of the severity scores from all the symptom tests as their overall severity score.

Our analysis showed that there was a decrease in the mean number and mean severity of shoulder symptoms at visit 4 compared to visit 1 in all treatment groups as illustrated in Figures 12 and 13. The improvement was the most significant for the exercise only group (Group 1), followed by the combined treatment group (Group 3).

An analysis of covariance was performed for both number of symptoms and severity level with the final value as the dependent variable, the initial value as the covariate, and treatment group as a factor. The analysis was done using raw and ranked data. In all analyses, the initial value was highly significant (p-value < 0.001). The treatment group factor was not significant for number of symptoms. However, for severity level, the treatment group factor was significant with the raw data (p-value = 0.017) and marginally significant with the ranked data (p-value = 0.058). Post-hoc analysis on the severity data showed a significant difference between treatment groups 1 and 3 (p-value = 0.005) and no significant difference between groups 1 and 2 (p-value = 0.096) or groups 2 and 3 (p-value = 0.180).

Comparison of the before and after treatment values for hip extensor, knee extensor and combined hip and knee extensor strength showed no significant change ($p > 0.05$) in any of the strength measures for any of the treatment groups.

DISCUSSION

The results of this study show that the mean number and severity of shoulder symptoms decreased for all three treatment groups, with the largest difference in before and after treatment values seen in the exercise-only group. Compliance was believed to be an issue in the difference between this group and the combined treatment group. Surprisingly, our results also indicated that, despite a significant improvement in the number and severity of shoulder symptoms, there was no significant change ($p > 0.05$) in mean isometric knee extensor or mean isometric hip extensor strength for any of the groups when we compared pre- and post-treatment values. One possible explanation is that the exercises were not of high enough intensity to induce a change in strength. However, they may have been sufficient to induce a change in endurance level. Unfortunately, our protocol did not include a test for change in endurance level. We did see a significant increase in the number of repetitions performed at the beginning of the treatment program compared to the end for both the exercise-only and the combined treatment group, which would tend to support the theory of a change in endurance. This difference was larger in the exercise-only group which was also the group that showed the largest degree of symptom resolution.

STUDY #7: EFFICACY OF ORTHOTIC INTERVENTION IN ALTERING PATTERNS OF MUSCLE USE AND IN RELIEVING SYMPTOMS OF PLANTAR FASCIITIS IN PATIENTS WITH AND WITHOUT POST-POLIO SYNDROME

RATIONALE

Plantar fasciitis is common to both polio survivors and military recruits and, in many instances is believed to result from biomechanical factors. An orthosis which alters the pattern of muscle use in the lower extremity should, therefore, hasten resolution of symptoms in both groups. Although ankle-foot

orthoses (AFOs) can alter forces and muscle activity in polio survivors with significant muscle weakness, molded shoe inserts, which could be used feasibly in the military or civilian populations, can have a similar effect on plantar fasciitis in individuals with milder weakness.

OBJECTIVES

1) to determine the effect of short leg braces or shoe inserts on the pattern of muscle use in subjects with plantar fasciitis and on resolution of symptoms.
2) to determine if the orthotically-induced change in muscle use is predictive of resolution of overuse symptoms over a one-month period.

METHOD

Subjects

Ten polio survivors with plantar fasciitis were recruited from the longitudinal study (#2), and 18 subjects with plantar fasciitis were recruited from the orthopedic practices of AEMC. One polio subject dropped out of the study after the second visit due to personal reasons. The criteria for subject selection was as follows:

1) had symptoms commonly associated with plantar fasciitis (heel pain and plantar fascia tenderness)
2) did not already wear a leg brace or shoe insert on the affected foot or have a foot that lacked feeling
3) did not have any major disability which might affect the use of his/her muscles
    e.g. stroke, amputation, diabetes, peripheral neuropathy, inflammatory arthritis, muscular dystrophy
4) able to walk unassisted.

Procedure

Partcipation in this study required four visits. At the first visit, a mold was taken for a custom orthosis (shoe insert for controls; AFO for polio survivors) and severity of symptoms of plantar fasciitis was rated on a visual analog scale. Shoe inserts were prescribed in two different sizes (one had a 3/8" heel lift and the other had a 1/4" heel lift) and were randomly distributed to the control subjects. Two brace or AFO prescriptions, which varied by the degree of dorsiflexion allowed (either 0° or 5°), were randomly distributed to the polio subjects.

At the second visit, which was approximately 1-2 weeks after the first visit, the orthosis was fitted and the subject was told to wear it for 5-7 days to become accustomed to it. Subjects were also told to place a pillow under their bed covers while they were sleeping so their foot would not point down during the night , and to ice or heat the bottom of the affected foot twice a day for 10 minutes. They were also given a stretching exercise designed to stretch the Achilles tendon (heel cord) and told to perfom the exercise as instructed twice a day. At the end of the 5-7 day period, the subject returned for a gait evaluation.

The gait evaluation was performed with and without the orthosis in random order and consisted of kinetic, kinematic, and dynamic electromyographic (EMG) data of 6 leg muscles. Bipolar surface EMG electrodes were affixed with double-sided adhesive after cleaning and abrading the skin. Surface EMG data was collected from the rectus femoris, vastus medialis and lateralis, tibialis anterior, soleus, and biceps femoris (long head). Bilateral heel and toe switch data were also recorded for stride identification. Walking speed was recorded, but not regulated. Subjects were asked to try to maintain their normal walking speed for all trials. Average walking speed was measured with a string tachometer. Ground reaction forces and moments were recorded with two AMTI forceplates mounted flush with the walkway surface.

Knee and ankle kinematic values were recorded using a three-camera Selspot optoelectromic motion analysis setup. Markers were placed on the lateral aspect of the affected limb (two markers on shoe to define foot vector, one marker midway between the lateral border of the patella and fibular head, and another along the line of the femur), on the unaffected limb, and on the pelvis. Footswitch, EMG, and kinematic marker lead wires were bundled on the subject's back and then run to an overhead trolley which moved along with the subject as he/she walked.

EMG and footswitch data was collected at 500 Hz., while tachometer and kinematic data was sampled at 125 Hz. Subjects were asked to walk 20-30 times as normally as possible along a walkway which was 30 ft. long.

As completion of the gait evaluation, the subjects were asked to continue to wear the orthosis whenever they were up on their feet. They returned 4-6 weeks later for a re-evaluation of their symptoms on a visual analog scale.

Predictions

Prior to beginning this study, we predicted that the use of the orthotic (brace or shoe insert) would result in decreased effort of the gastrocsoleus or reduced plantar flexor activity and amount of pull (illustrated by a decrease in EMG activity or area under the curve for the soleus and/or change in time of onset/offset time). We predicted that the degree of EMG reduction would be predictive of symptom resolution. In addition, in terms of the kinematic data, we predicted that the use of the orthotic would result in an increase in the plantar flexion moment at the ankle, which would be illustrated by less dorsiflexion at the ankle, and decreased activation of the knee extensor, which would be illustrated by a decrease in rectus femoris activation during the stance phase and an increase in the extensor moment for the knee. These changes would be more significant for the brace with more limited dorsiflexion (0°) and the higher insert (3/8").

PRELIMINARY ANALYSIS AND RESULTS

A within-subjects comparison of the pre- and post-treatment severity ratings showed a significant difference for both braces (Wilcoxon p-value = 0.008) and inserts (Wilcoxon p-value = 0.001). Among the 9 subjects who received braces, all showed a reduction in symptom severity after wearing their brace for 7-9 weeks. Among the 18 subjects who received inserts, 17 showed an improvement in symptom severity after wearing their insert for 7-9 weeks.

An analysis of covariance with the final severity rating as the dependent variable, the initial severity as the covariate, and prescription as the grouping factor showed no significant difference between prescriptions for either braces or inserts. The analysis was repeated using ranked data, and the results were the same. The difference in prescriptions did not affect the degree of symptom resolution.

A repeated measures analysis with initial and final severity as the repeated measures and prescription as the grouping factor revealed a significant time effect for both braces and inserts. However, effect of the different prescriptions were not significantly different and neither was the interaction between time and prescription for braces or inserts.

An analysis of the overall area under the curve for the EMG activity from an entire stride (full gait cycle) comparing the condition with the orthotic versus without the orthotic showed no significant differences for either braces or inserts for any of the muscles involved (rectus femoris, vastus medialis and lateralis, tibialis anterior, soleus, and biceps femoris).

The muscle group where we predicted we would see the most change due to the presence or absence of the orthotic was the soleus muscle. In order to determine if there were any changes in soleus activity related to different phases of the gait cycle, the area under the curve was divided into 5% intervals. We focused our analysis on two specific intervals where the soleus was most active: 15-45% which corresponded to the eccentric phase of contraction (early to mid stance) and 50-60% which corresponded to the concentric phase of contraction (mid to late stance).

The results of comparisons between the condition with the orthotic and without the orthotic for both intervals revealed a significant difference between conditions for the insert group only in the 50-60% interval (Wilcoxon p-value = 0.019). Within this interval, 15 out of 18 subjects had greater soleus activity with the orthotic compared to without. To confirm these results, a bootstrap resampling simulation was run comparing the area under the curve for both intervals between the condition with the orthotic and without. The results of this analysis showed a significant difference for the 50-60% interval at the 0.025 level for inserts only. All other comparisons showed no significant differences.

We had predicted that the change in EMG activity would be predictive of the degree of symptom resolution. A Spearman correlation analysis showed that there was no significant correlation between change in area under the curve (50-60% interval) and change in symptom severity.

A multiple regression analysis was performed using the area under the curve for the soleus muscle (50-60% interval) without the orthotic and initial severity rating to predict the final severity rating. The results showed that the area under the curve for the 50-60% interval was a highly significant predictor (p-value = 0.008) for inserts only. However, when the analysis was repeated using percent change in area for the soleus (50-60% interval), none of the variables were significant.

Data analysis is continuing for the proximal muscle activity and proximal joint kinematics, as well as kinetics. This is expected to provide further insight into the biomechanical changes which occurred as a result of orthotic intervention.

PRELIMINARY DISCUSSION

Our original hypothesis predicted a decrease in EMG activity, particularly in the soleus, with the use of the orthotic which would correlate with a reduction in symptom severity. To date, our results have not supported this hypothesis. Instead, we found a significant increase in soleus activity during the concentric phase of contraction or during the mid to late stance phase of the gait cycle when the orthotic

was worn compared to when the orthotic was not worn. This change in muscle activity was significant for inserts only. We did not see any significant differences in EMG activity or symptom resolution between the two insert prescriptions.

Because we saw an increase in soleus activity with the insert, we speculated that resolution of pain caused a reduction of the compensatory mechanisms associated with plantar fasciitis. The end result was that observed gait became more efficient and "normal".

There was a trend towards decreased plantar flexor activity during the early to midstance phase and an increase in plantar flexor activity during mid to late stance phase of the gait cycle. We hypothesized that the reduction in pain allowed subjects to roll over the foot during the weight acceptance and loading phases of gait in a less restricted manner. In other words, there was a decrease in the "avoidance" strategy (i.e. mechanisms to avoid loading or fast application of full weight on the painful foot are decreased). Normally, the plantar flexors restrain tibial rotation in the mid stance phase, but pain reduction may allow the subjects to "let go" more and let the tibia/fibula roll over the foot in a more natural manner. Similarly, pushoff, which is driven by the plantar flexors, may also be greater now if the foot is less painful. This would correlate with an increase in plantar flexor activity in mid to late stance, as was observed.

It should be noted that while the analysis across all subjects with braces showed no consistent trends, there were significant changes in the muscle activation patterns when data was assessed on an individual basis. Because the subjects who received braces (polio survivors) tended to be weaker than the subjects who received inserts (controls), it is possible that the compensation mechanisms employed by the polio survivors with foot pain were much more complex than those used by the controls. Unfortunately, we were unable to reliably characterize the patterns involved among the polio survivors due to the small sample size.

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APPENDIX I

FIGURES

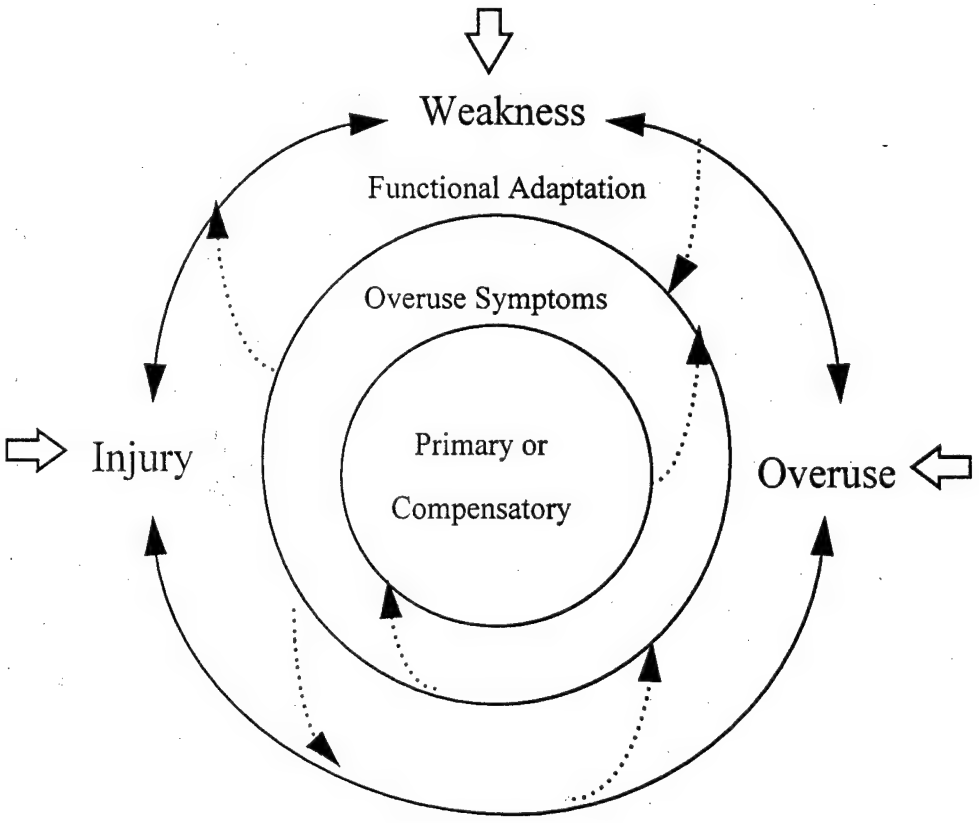

Figure 1. Relationship between weakness, overuse, and injury. Individuals enter the cycle at different points and at different levels of weakness. However, once in the cycle, they are all prone to injury via the same biomechanical meehanisms.

Post Polio

Patient Sample Population Survey

PERCENT

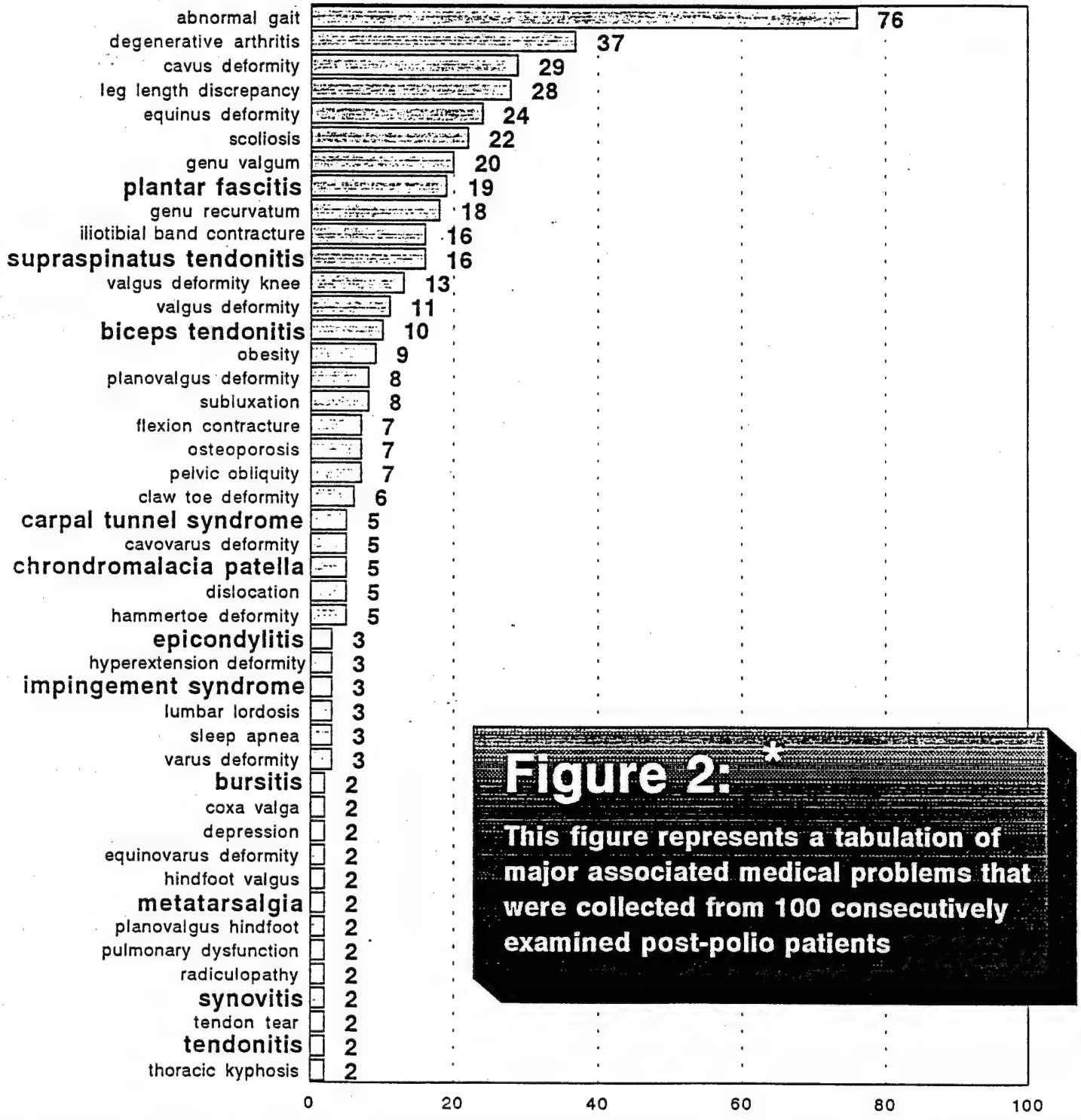

Figure 2: *

This figure represents a tabulation of major associated medical problems that were collected from 100 consecutively examined post-polio patients

* medical problems in bold text are specifically related to the Overuse Syndrome

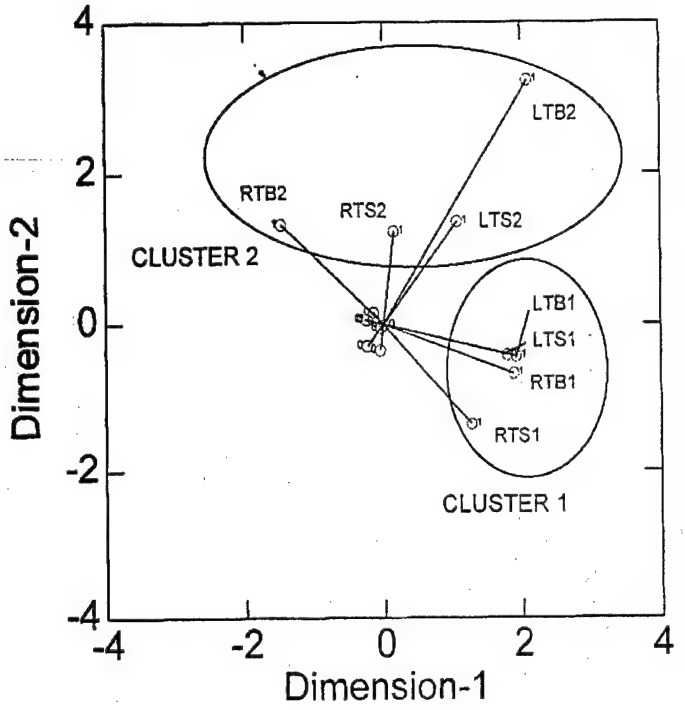

Figure 3. Results of the cluster analysis of shoulder symptoms. Symptoms that co-occur appear closer together in this arbitrary two-dimensional space than those that are unrelated. The presence of a symptom is represented by a "1" and the absence of a symptom is represented by a "0" (grouped near the center). Cluster 1 contains symptoms of left biceps palpation pain (LTB1), right biceps palpation pain (RTB1), left supraspinatus palpation pain (LTS1), and right supraspinatus palpation pain (RTS1). Cluster 2 contains symptoms of left supraspinatus (impingement) pain (LTS2), right supraspinatus (impingement) pain (RTS2), left biceps resistance pain (LTB2), and right biceps resistance pain (RTS2).

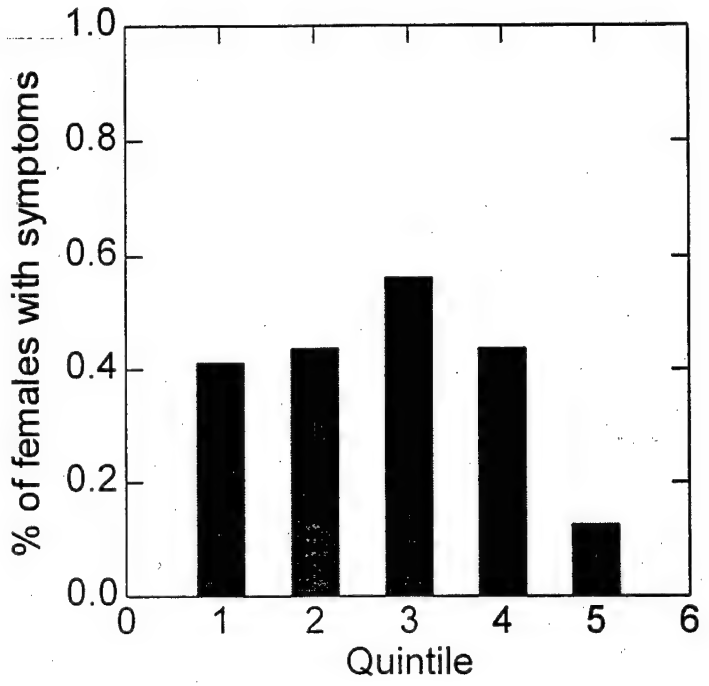

Figure 4. Relationship between knee extensor strength and the proportion of females with Cluster 1 (palpation) symptoms. Quintiles of strength among females are shown along the X axis, arrayed from weakest to strongest. The proportion of women with palpation-provoked symptoms in each quintile is shown on the Y axis.

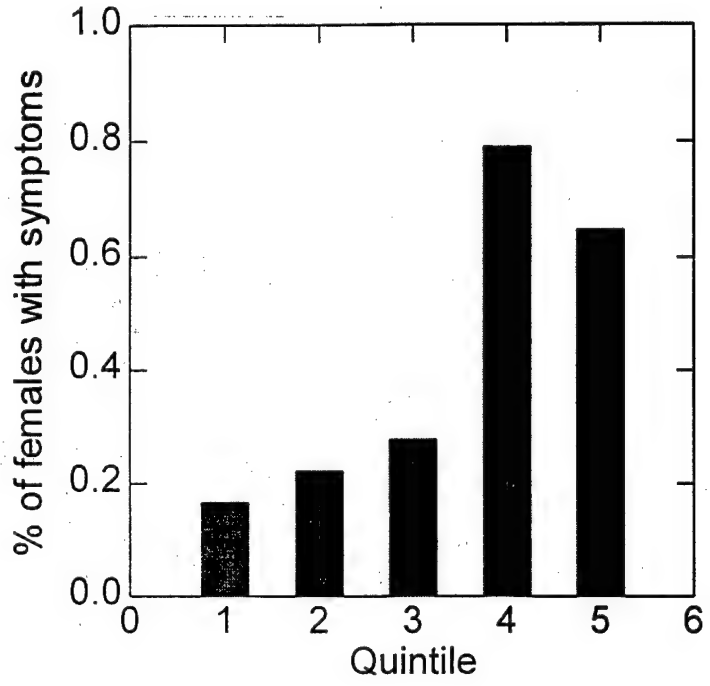

Figure 5. Relationship between weight and the proportion of females with Cluster 1 (palpation) symptoms. Quintiles of weight, arrayed from lightest to heaviest, are shown on the X axis. The bars represent the proportion of women with Cluster 1 (palpation) symptoms in each quintile.

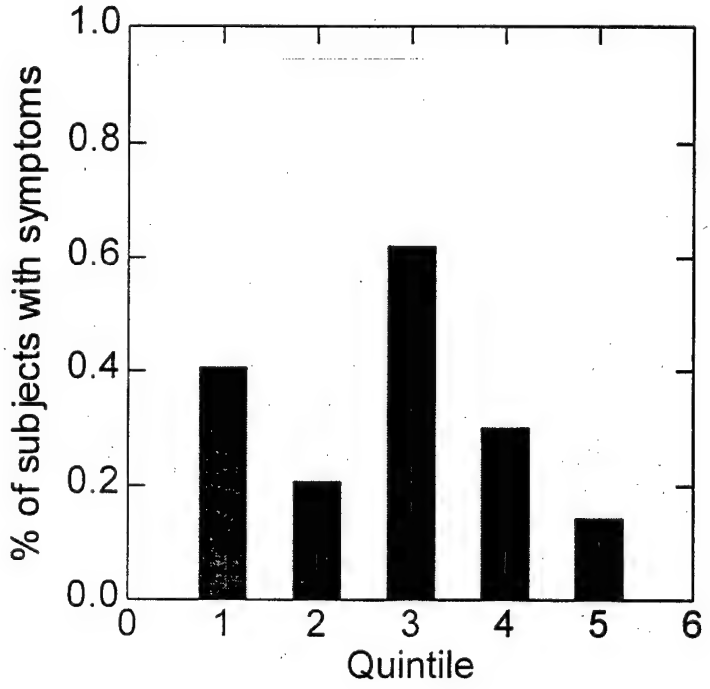

Figure 6. Relationship between total leg extensor strength (ALL) and the proportion of subjects with Cluster 2 (resistance) symptoms. The quintiles of strength are arrayed from weakest to strongest along the X axis, and the proportion of subjects with resistance-induced symptoms in each quintile is shown on the Y axis.

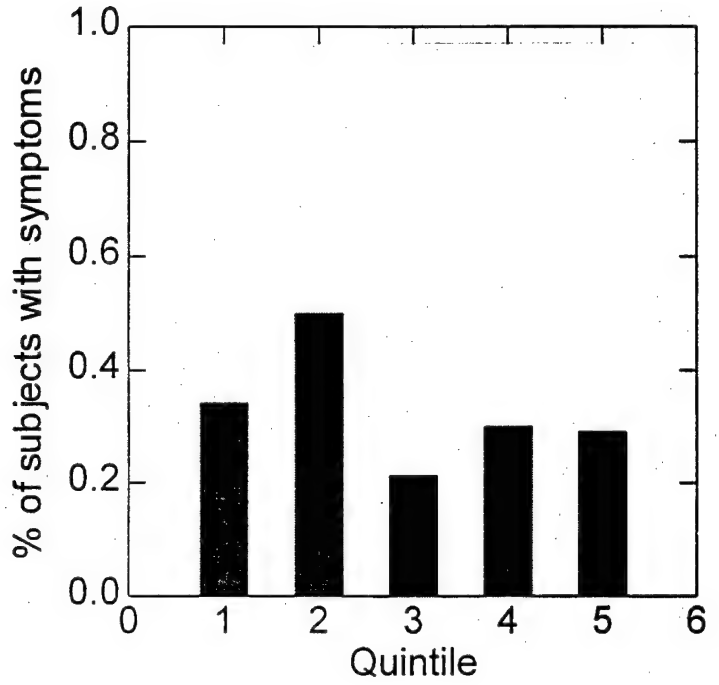

Figure 7. Relationship between age and the proportion of subjects with Cluster 2 (resistance) symptoms. The quintiles of age are ordered from youngest to oldest along the X axis. The bars represent the proportion of subjects in each quintile with resistance-induced symptoms.

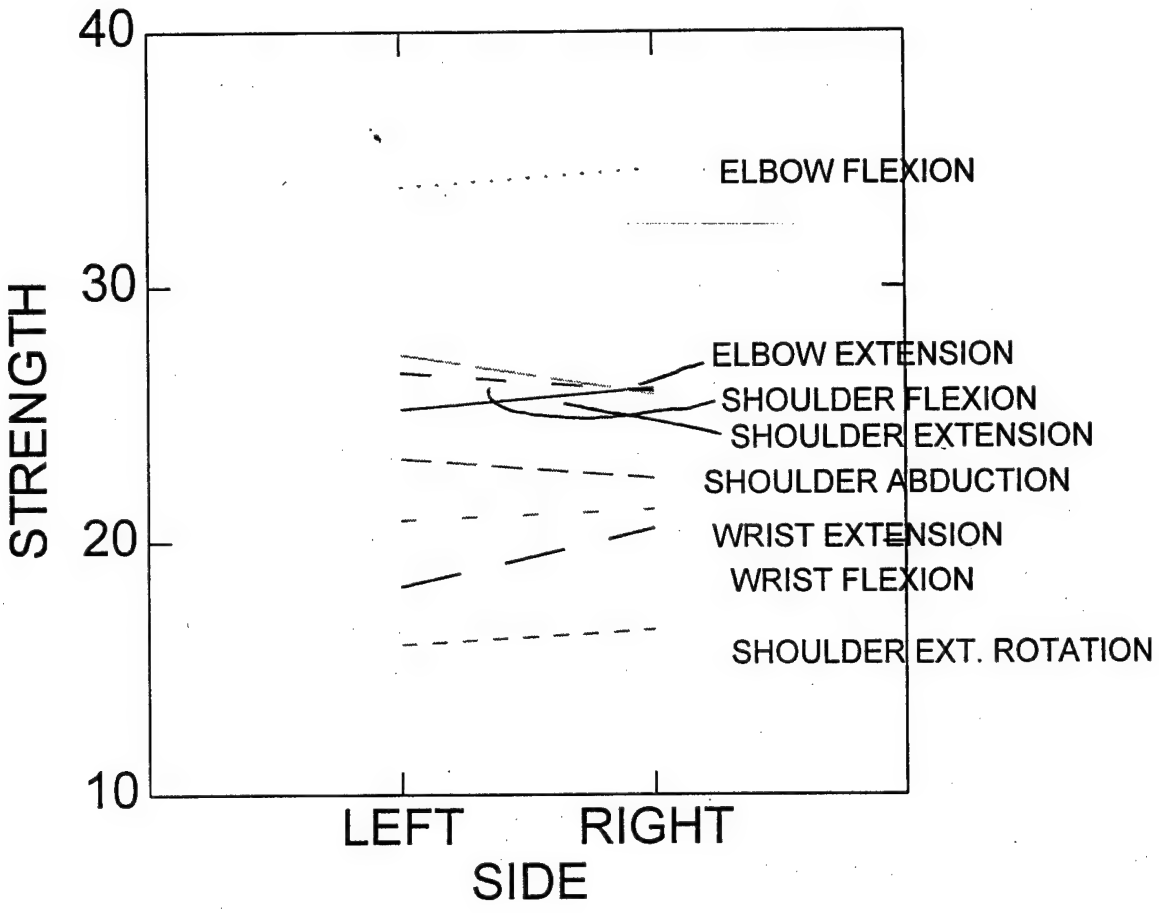

Figure 8. Interaction between muscle and side for upper body muscle groups.

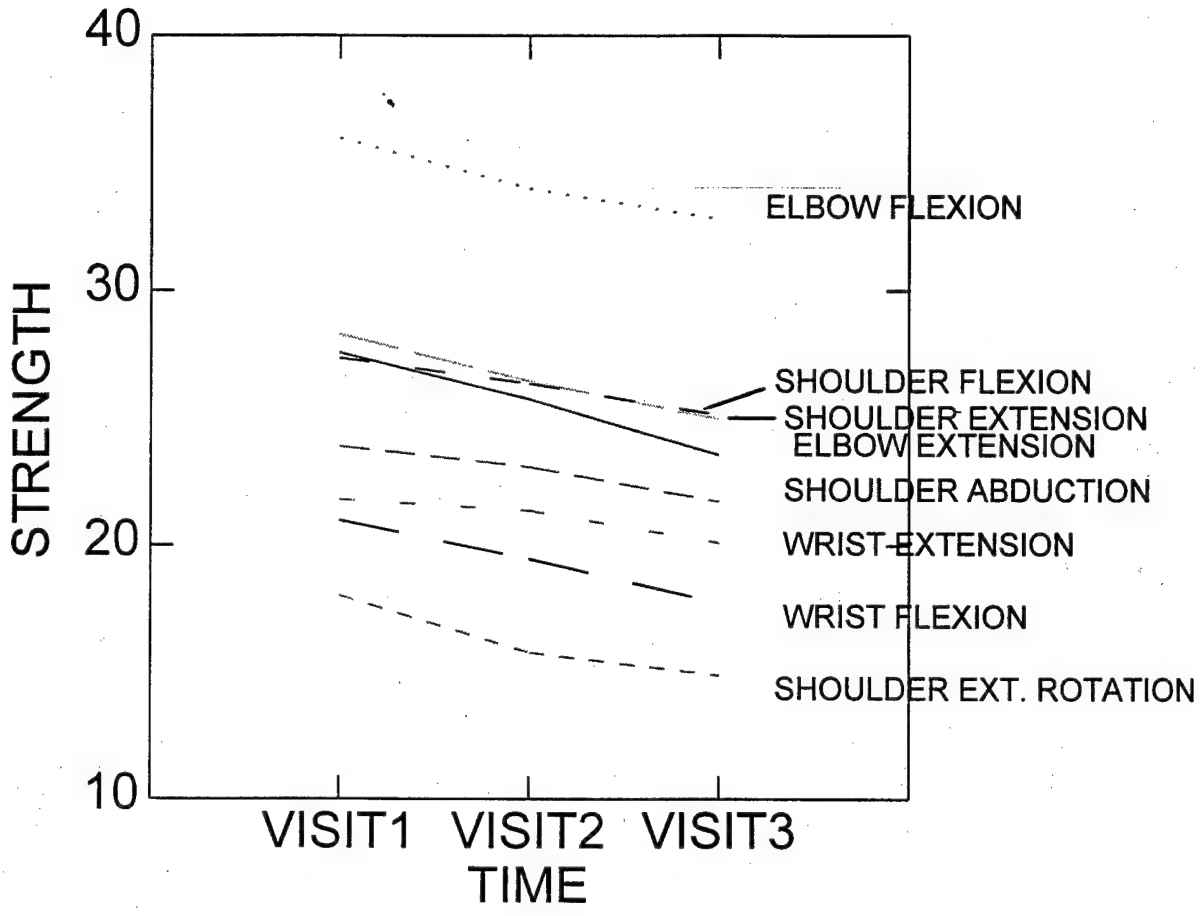

Figure 9. Interaction between muscle and time for upper body muscle groups.

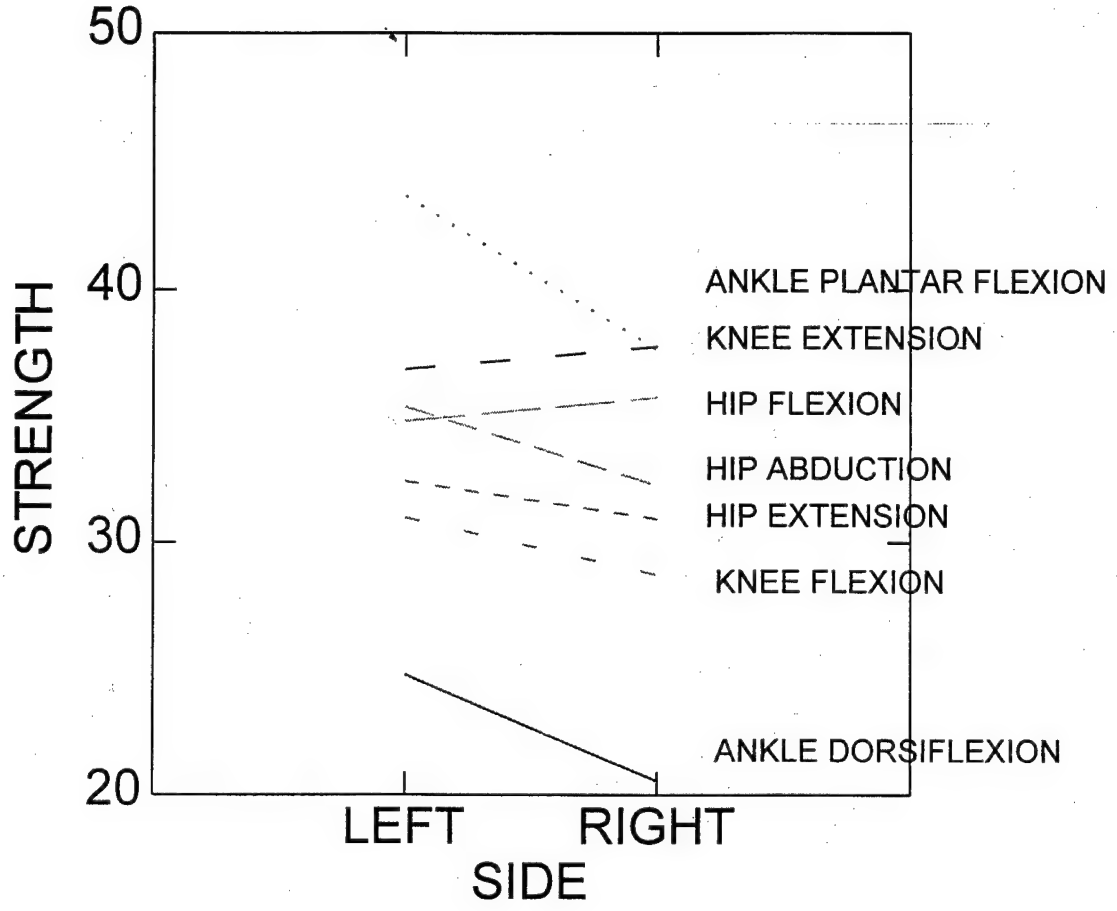

Figure 10. Interaction between muscle and side for lower body muscle groups. The plot shows the mean strength (lbs) for the left and right sides of the body.

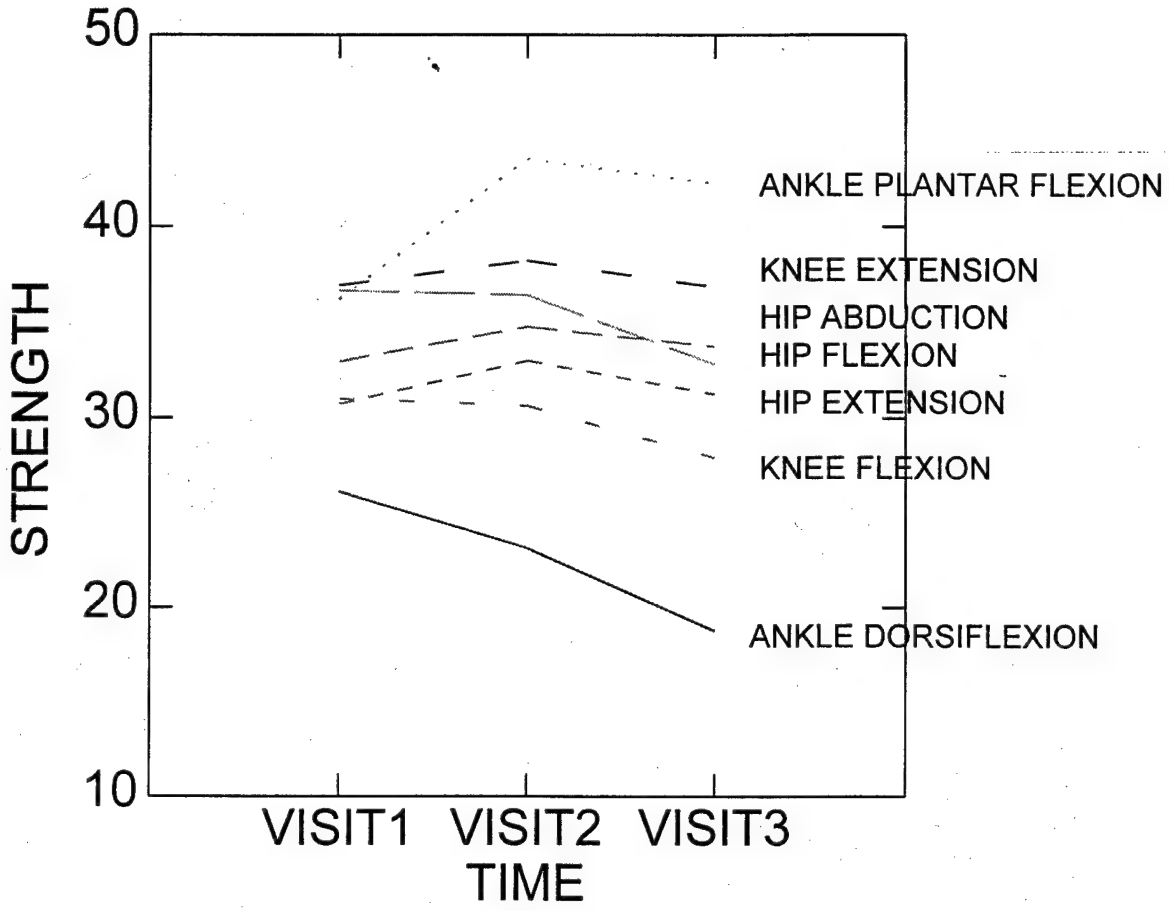

Figure 11. Interaction between muscle and time for lower body muscle groups. The plot shows the change in mean strength (lb) from visit 1 to visit 3.

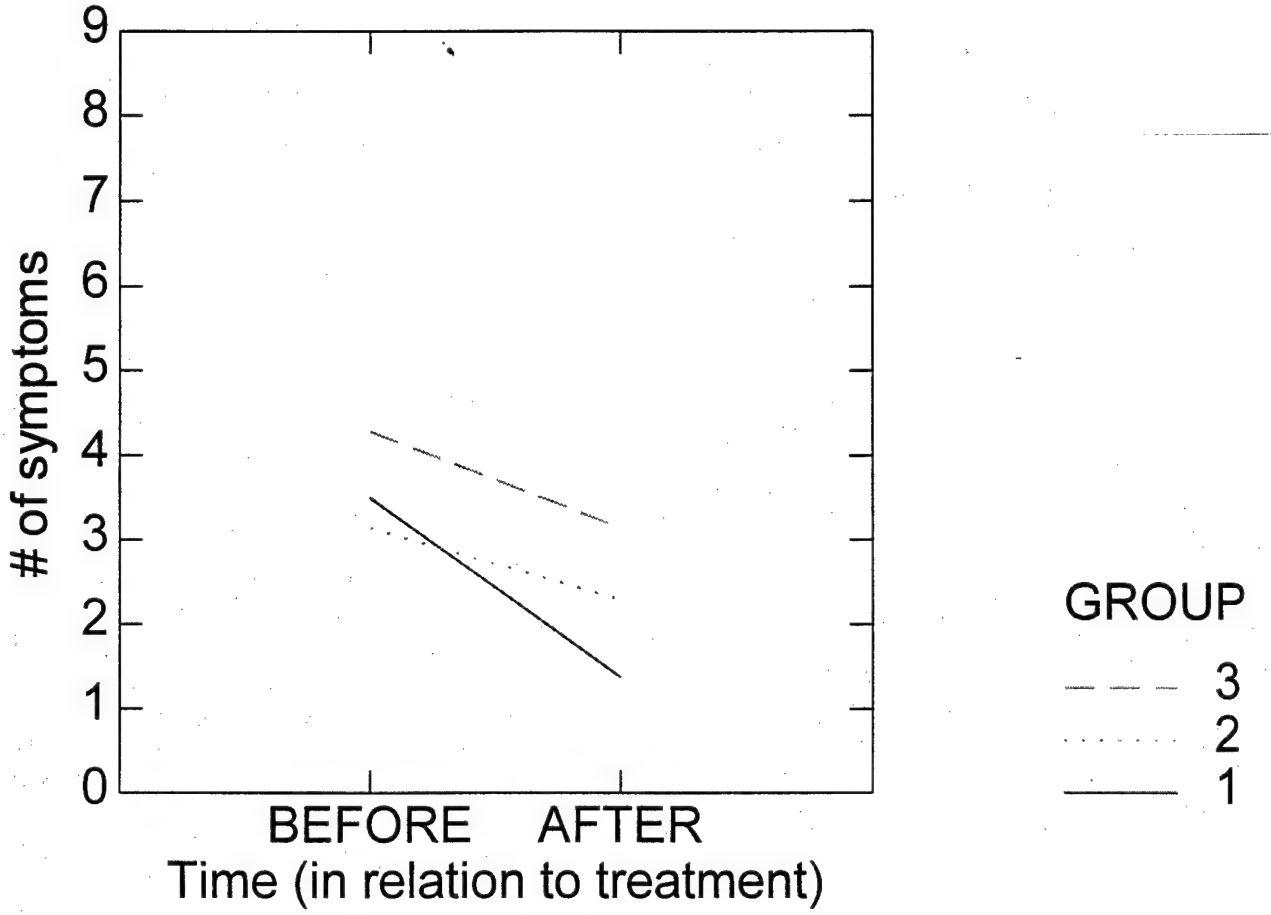

Figure 12. Plot of the mean number of symptoms for each group before and after treatment.

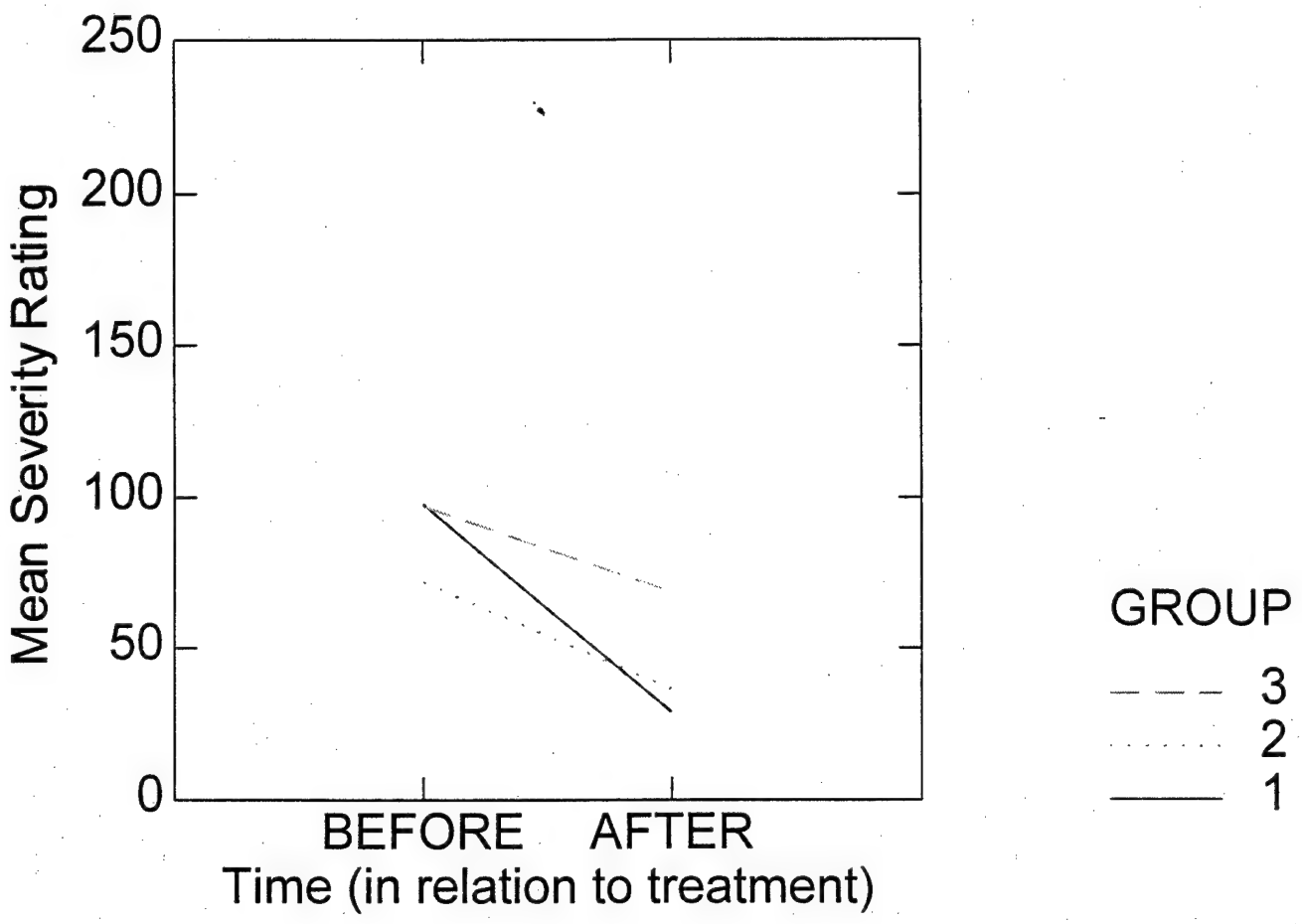

Figure 13. Plot of the mean severity rating (from VAS scale) for each group before and after treatment.

APPENDIX II

TABLES

Table 1. Symptom Evaluation Protocol

Location	Test	Position	Procedure
	Biceps Palpation	Shoulder in neutral rotation; elbow flexed 90°; forearm supinated	Pressure applied in bicipital groove on anterior shoulder
Shoulder	Supraspinatus Palpation	Arm relaxed at side	Pressure applied on tendon insertion site just proximal to greater tuberosity of humerus
	Supraspinatus Test (Impingement)	Shoulder abducted 90°; elbow fully extended; thumb pointing towards floor	Examiner pushes on arm above elbow while subject resists
	Biceps Test	Shoulder in neutral; elbow flexed 90°	Examiner attempts to supinate forearm while subject resists
	Lateral Epicondyle Palpation	Shoulder in neutral; elbow flexed 45°	Gentle pressure applied to lateral bony prominence at elbow
Elbow	Medial Epicondyle Palpation	Shoulder in neutral; elbow flexed 45°	Gentle pressure applied to medial bony prominence at elbow
	Resisted Wrist Flexion	Elbow flexed 90°; wrist in neutral position	Gentle pressure applied to hand while subject resists
	Resisted Wrist Extension	Elbow flexed 90°; wrist in neutral position	Gentle pressure applied to palm while subject resists
	Numbness/Tingling/Arm/ Wrist/Hand		Examiner questioned subject if symptoms experienced; if so, description requested
	Phalen's Test	Shoulders relaxed, internally rotated, elbows at 90°; wrists in palmar flexion, hands placed together	Subject instructed to apply gentle pressure to hands and hold position for 30 seconds
Wrist	Tinel's Test	Forearm supinated; wrist neutral	Examiner gently taps volar surface of wrist region
	Thenar Atrophy	Forearm supinated; wrist neutral	Palmar surface of thumb examined
	Adson's Maneuver	Shoulder abducted with elbow fully extended out at side	Examiner locates radial pulse, then positions arm and requests the subject to turn and look over opposite shoulder
	Plantar Fascia Tenderness	Ankle in dorsiflexion	Pressure applied to plantar fascia tendon
Ankle/	Cavus	Feet positioned flat on floor	Examiner observed for high arch
Foot	Equinus	Heel placed in palm of examiner's hand	Examiner observed for dropped toes
	Valgus	Feet positioned flat on floor	Examiner observed for absence of arch
Back	Scoliosis	Sitting with hips/knees at 90°	Scapula examined for inequality; spine palpated for curvature
	Pelvic Obliquity	Sitting with hips/knees at 90°	Iliac crests examined for asymmetry
	Greater Trochanter	Lying supine with legs in full extension	Hip joint palpated by examiner
Hip	Resisted Abduction	Lying supine with legs in full extension	Gentle resistance applied at calf while subject instructed to abduct leg
	Patello-femoral Crepitation	Lying supine with legs straight, relaxed	Using thumb and index finger, examiner gently pushes the patella downward, then asks the subject to contract the knee extensors
Knee	Knee Valgus	Lying supine with legs straight	Examiner draws a visual line from the iliac spine to midpoint of medial and lateral malleolus
	Iliotibial Band (ITB) Contracture	Lying supine with legs straight	Examiner places hand along ITB , raises leg and tries to move it across midline

TABLE 2. STRENGTH TESTING PROTOCOL

Muscle Group	Position	Limb Position	Dynamometer Placement	Stabilization Point
Neck Extension	Sidelying	Neck at neutral	Base of skull	None
Shoulder Flexion	Sidelying	Shoulder flexed 90° ; elbow extended	Midshaft of humerus	Anterior aspect of shoulder
Shoulder Extension	Sidelying	Shoulder at neutral; elbow flexed 90°	Proximal to olecranon	Anterior aspect of shoulder
Shoulder Abduction	Supine	Shoulder abducted 90°	Midshaft of humerus	Anterior aspect of shoulder
Shoulder Ext. Rotation	Sitting	Shoulder at neutral; elbow flexed 90°	Just proximal to ulnar styloid	Contralateral shoulder
Elbow Flexion	Sidelying	Shoulder at neutral; elbow flexed 90°	Palmar surface of forearm; proximal to wrist	Shoulder
Elbow Extension	Sidelying	Shoulder at neutral; elbow flexed 90°	Proximal to ulnar styloid; dorsal surface of forearm	Shoulder
Wrist Flexion	Sitting	Shoulder at neutral elbow flexed 90°	Dorsal aspect of hand	Forearm
Wrist Extension	Sitting	Shoulder at neutral; elbow flexed 90°	Palmar aspect of hand	Forearm
Hip Flexion	Sidelying	Leg positioned on raised powder board; hip flexed 30°; knee flexed	Proximal to superior side of patella	Pelvis
Hip Extension	Sidelying	Leg positioned on raised powder board; hip neutral; knee extended	Proximal to popliteal crease	Pelvis
Hip Abduction	Supine	Hip abducted to 45° ; with contralateral hip neutral	Proximal to superior pole of patella on lateral aspect of thigh	Hip
Knee Flexion	Sidelying	Leg positioned on raised powder board; hip flexed 10°; knee flexed 30°	Proximal to maleoli on posterior aspect of calf	Anterior aspect of femur
Knee Extension	Sidelying	Leg positioned on raised powder board; knee flexed 45°	Proximal to malleoli on anterior aspect of tibia	Femur
Ankle Dorsiflexion	Supine	Hip, knee, and ankle neutral	Metatarsals	Tibia
Ankle Plantar flexion	Supine	Hip, knee, and ankle neutral	Metatarsal heads	Tibia

Table 3. Reliability Results for Strength Testing

Muscle Group	Dominant	Range (lbs)	Non-dominant	Range (lbs)
Neck Extension	0.581	9.6-44		
Shoulder Flexion	0.933	5.6-37.75	0.810	8.9-37.5
Shoulder Extension	0.714	8.0-52.1	0.745	9.0-83.3
Shoulder Abduction	0.948	5.9-40.0	0.952	6.2-36.5
Shoulder Ext. Rotation	0.868	5.2-23.5	0.848	5.0-23.25
Elbow Flexion	0.894	10.2-51.5	0.851	12.6-52.25
Elbow Extension	0.922	10.3-39.75	0.727	11.3-39.0
Wrist Flexion	0.740	11.2-31.0	0.703	8.2-31.5
Wrist Extension	0.809	6.3-29.0	0.917	5.0-27.5
Hip Flexion	0.683	13.7-69.7	0.779	7.6-71.1
Hip Extension	0.787	4.1-63.2	0.917	0-64.0
Hip Abduction	0.819	10.9-68.5	0.895	0-58.0
Knee Flexion	0.937	9.0-59.5	0.977	0-51.0
Knee Extension	0.943	19.3-83.3	0.965	3.0-84.5
Ankle Dorsiflexion	0.915	2.5-50.5	0.925	0-51.0
Ankle Plantar Flexion	-0.130	26.0-80.0	0.753	0-82.0

Table 4. Symptom Inter-Rater ReliabilityResults

N=16

Symptom	p_o
Biceps Palpation	96%
Supraspinatus Palpation	96%
Impingement Test	84%
Biceps Test	91%
Lateral. Epicondyle Palpation	98%
Medial Epicondyle Palpation	94%
Resisted Writst Flexion	96%
Resisited Wrist Extension	96%
Numbness/Tingling	84%
Phalen's Test	96%
Tinel's Test	100%
Thenar Atrophy	100%
Adson's Manuever	90%
PF Tenderness	96%
Cavus (Foot)	95%
Equinus (Foot)	85%
Valgus (Foot)	91%
Scoliosis	73%
Pelvic Obliquity	95%
Palpation Greater Trochanter	94%
Patella-femoral Crepitation	71%
Knee Valgus	85%
Ilial Tibial Band Contracture	100%

Table 5. Summary of Dynamometer Reliability Results
Mean(SD)
N=10

Muscle Group	Hand - Held Dynamometer		Kin- Com	
	Left	Right	Left	Right
Knee Flexion	31.45 (14.29)	26.61 (10.53)	31.91 (16.23)	28.68 (11.26)
Knee Extension	42.48 (21.27)	38.18 (12.17)	48.00 (18.22)	47.69 (14.80)*
Elbow Flexion	37.04 (12.86)	36.28 (10.22)	38.30 (13.54)	42.64 (17.70)
Elbow Extension	27.96 (11.47)	24.57 (8.97)	24.31 (7.98)	24.32 (6.62)

*Wilcoxon showed significant differences between groups ($p<0.05$)

Table 6. Polio Subject Characteristics

Gender	N	Age (yr) Mean (SD)	Weight (kg) Mean (SD)	Height (cm) Mean (SD)
Males	98	59.14 (10.8)	87.03 (18.8)	175.87 (9.06)
Females	96	56.15 (9.1)	69.24 (14.9)	161.31 (7.37)

TABLE 7. RESULTS OF SYMPTOM, SIGN AND DEFORMITY ASSESSMENT

Location	Symptom/Sign/Deformity	Number of Positive Responses Left	Right
Shoulder	Biceps palpation	24 (12%)	19 (10%)
	Supraspinatus palpation	22 (11%)	10 (5%)
	Supraspinatus test	34 (18%)	40 (21%)
	Biceps test	2 (1%)	3 (2%)
Elbow	Lat. epicondyle palpation	6 (3%)	6 (3%)
	Med. epicondyle palpation	4 (2%)	12 (6%)
	Resisted wrist flexion	1 (0.5%)	4 (2%)
	Resisted wrist extension	4 (2%)	4 (2%)
Wrist	Numbness/tingling/arm/wrist/hand	51 (26%)	47 (24%)
	Phalens test	21 (11%)	19 (10%)
	Tinels test	5 (3%)	4 (2%)
	Thenar atrophy	22 (11%)	18 (9%)
	Adson's manuever	4 (2%)	4 (2%)
Back	Scoliosis	80 (41%)	
	Pelvic obliquity	47 (23%)	
Hip	Palpation greater trochanter	11 (6%)	18 (9%)
	Resisted abduction	8 (4%)	6 (3%)
Knee	Patellofemoral crepitation (no pain)	109 (56%)	103 (53%)
	Patellofemoral crepitation (pain)	13 (7%)	9 (5%)
	Knee valgus	31 (16%)	39 (20%)
	Iliotibial band contracture	10 (5%)	10 (5%)
Ankle/foot	Plantar fascia tenderness	39 (20%)	19 (20%)
	Cavus	80 (41%)	75 (39%)
	Equinus	54 (28%)	60 (31%)
	Valgus	29 (15%)	33 (17%)

Table 8. Results of Comparison of Ankle Plantar Flexor Strength in Legs with Patella-Femoral Crepitation (with or without knee pain) and Legs without Knee Symptoms

DOMINANT SIDE

Braces	Quads**	Ankle Plantar Flexor Strength* Symptomatic	Asymptomatic	Mann-Whitney U p-value
No	Strong	N = 54 37.794(16.0)	N = 75 39.001(17.2)	0.563
No	Weak	N = 5 5.500(5.5)	N = 5 34.270(23.4)	0.004
Yes	Strong	N = 9 18.500(14.3)	N = 10 21.230(16.4)	0.744
Yes	Weak	N = 4 1.125(2.3)	N = 6 7.483(13.2)	0.695

NON-DOMINANT SIDE

Braces	Quads**	Ankle Plantar Flexor Strength* Symptomatic	Asymptomatic	Mann-Whitney U p-value
No	Strong	N = 47 38.681(18.5)	N = 60 39.305(15.4)	0.960
No	Weak	N = 3 21.133(8.4)	N = 9 21.056(20.8)	0.432
Yes	Strong	N = 7 9.486(9.4)	N = 14 14.529(13.0)	0.453
Yes	Weak	N = 15 3.947(7.7)	N = 8 5.680(10.4)	0.441

* - Mean (SD)

** - quadriceps (knee extensor) strength level based on MMT results

Table 9. Results of Comparison of Ankle Plantar Flexor Strength in Legs with Knee Pain and Legs without Knee Pain

DOMINANT SIDE

Braces	Quads**	Ankle Plantar Flexor Strength* Symptomatic	Asymptomatic	Mann-Whitney U p-value
No	Strong	N = 3 30.333(5.1)	N = 126 38.932(16.8)	0.563
No	Weak	N = 0 -	N = 10 21.236(21.4)	-
Yes	Strong	N = 2 20.425(10.8)	N = 17 19.879(158)	1.000
Yes	Weak	N = 0 -	N = 10 4.940(10.5)	-

NON-DOMINANT SIDE

Braces	Quads**	Ankle Plantar Flexor Strength* Symptomatic	Asymptomatic	Mann-Whitney U p-value
No	Strong	N = 2 24.900(22.1)	N = 105 39.544(16.6)	0.250
No	Weak	N = 0 -	N = 12 20.062(17.7)	-
Yes	Strong	N = 2 13.800(14.4)	N = 19 12.747(12.1)	0.453
Yes	Weak	N = 1 0.000	N = 22 5.113(8.9)	0.420

* - Mean (SD)

** - quadriceps (knee extensor) strength level based on MMT results

Table 10. Comparison of Regression Models

Model: KNEES and AGE

	Males	Females
Variable*	**Odds ratio**	Odds ratio
KNEES-1	**7.269**	5.549
KNEES-2	**3.952**	2.235
KNEES-3	**22.218**‡	4.838
KNEES-4	**2.095**	4.870
AGE-1	**2.154**	1.567
AGE-2	**16.396**‡	3.399
AGE-3	**11.759**†	0.310
AGE-4	**3.732**	1.215
Sensitivity	**0.758**	0.449
Specificity	**0.507**	0.693

Model: HIPS and AGE

	Males	**Females**
Variable*	Odds ratio	**Odds ratio**
HIPS-1	3.995	**10.032**†
HIPS-2	2.798	**2.860**
HIPS-3	3.819	**5.793**
HIPS-4	1.446	**6.406**†
AGE-1	0.855	**2.845**
AGE-2	3.979	**3.641**
AGE-3	4.050†	**0.395**
AGE-4	1.245	**1.863**
Sensitivity	0.435	**0.441**
Specificity	0.702	**0.725**

Note: The models which resulted from the stepwise multivariate analysis are in bold.

* - variables are in quintiles

† - $p < 0.05$

‡ - $p < 0.01$

Table 11. Ambulators Only
Mean (SD)

Side	N	Symptomatic		N	Asymptomatic	Mann-Whitney U Test p-value	Mann-Whitney U Test Statistic
Non-Dominant	18	19.106 (12.2)		159	30.174 (17.7)	0.014	924.50
Dominant	21	19.931 (10.0)		158	31.047 (14.9)	0.001	899.00

Table 12. Control Subject Characteristics

Gender	N	Age (yr) Mean (SD)	Weight (kg) Mean (SD)	Height (cm) Mean (SD)
Males	113	44.81 (17.1)	84.25 (16.6)	178.82 (7.37)
Females	113	45.82 (18.2)	74.04 (18.8)	162.79 (11.18)